Conceptual Design and Propulsion Airframe Integration Studies for the SUSAN Electrofan

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The SUbsonic Single Aft eNgine (SUSAN) Electrofan

What is SUSAN?
SUSAN is a transport category aircraft that uses a 20 MW class Electrified Aircraft Propulsion (EAP) system to enable advanced Propulsion-Airframe Integration (PAI). With alternative fuels and advanced technologies such as natural-laminar-flow wings, SUSAN has the potential to reduce fuel consumption and emissions by 50% per passenger/mile while retaining the size, speed, and range of large regional jets.

Problem:
Aircraft fuel consumption and emissions have to be reduced by at least a factor of two, with a goal of zero emissions.

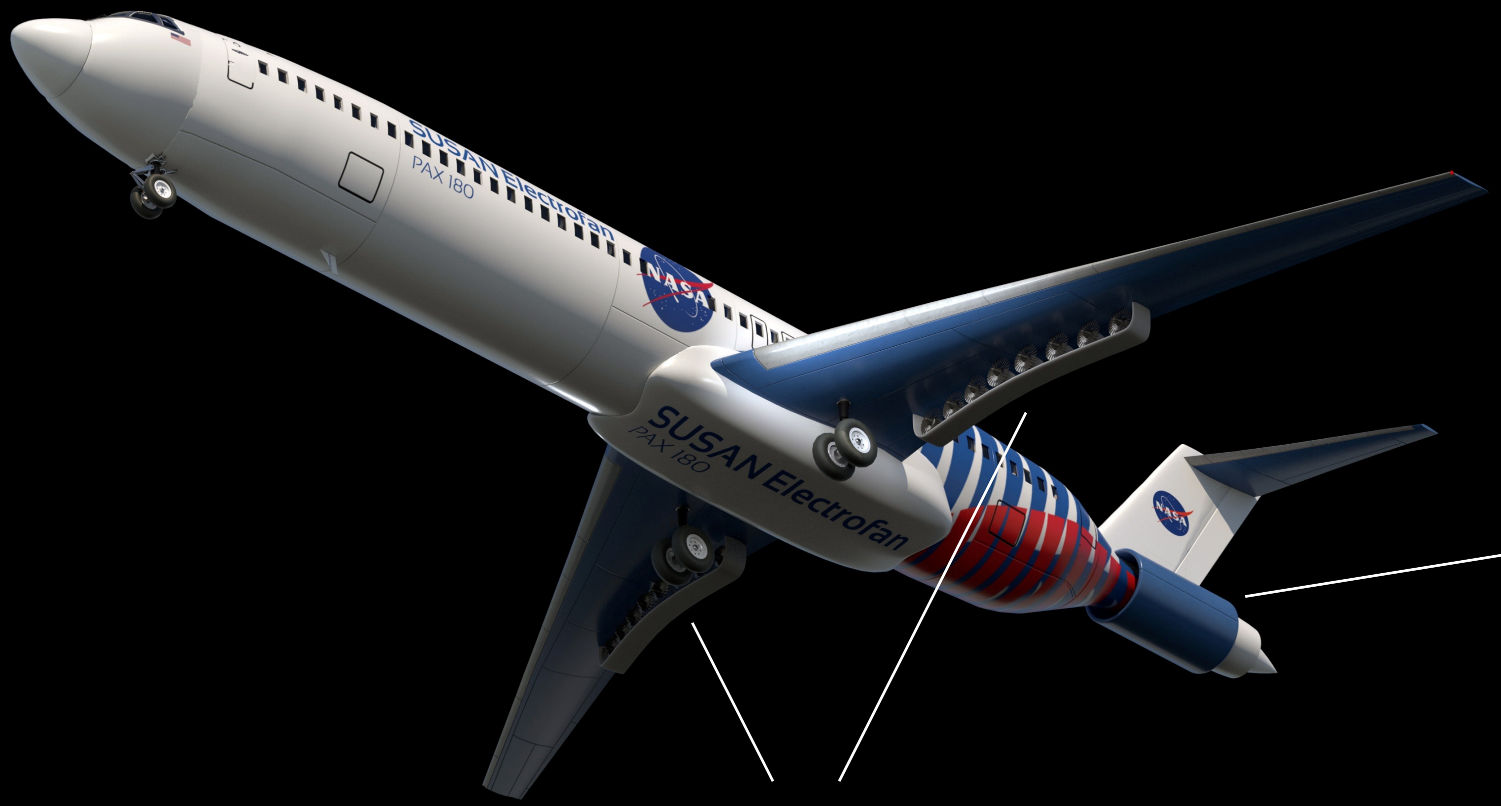
Constraints:
Must use existing airport infrastructure, be flight certifiable, and be more cost effective.

Solution:
Large Hybrid-Electric Aircraft

Principal Investigators:
Ralph Jansen (Co-PI, Glenn) and Cetin Kiris (Co-PI, Ames)

- **Transformative concept:** Single engine transport aircraft.
  - 4 engine transport aircraft achieved in 1949
  - 3 engine transport aircraft achieved in 1962
  - 2 engine transport aircraft achieved in 1965
  - Five decades later, single engine not yet achieved
- **Target market:** Regional low-cost carrier airline: 180 PAX, design range 2,500 nmi, economy range 750 nmi, Mach 0.785

The SUbsonic Single Aft eNgine (SUSAN) Electrofan



Class	Regional
Capacity	180 PAX
Design Range	2500 nmi
Economy Range	750 nmi
Mach Number	0.785

Preliminary concept only

AIAA SciTech 2022 Conference Papers

"Subsonic Single Aft Engine (SUSAN) Transport Aircraft Concept and Trade Space Exploration," Jansen et al., AIAA 2022-2179

"Initial Regulatory and Certification Approach for the SUSAN Electrofan Concept," Denham et al., AIAA 2022-2180

"Conceptual Exploration of Aircraft Configurations for the SUSAN Electrofan," Chau et al., AIAA 2022-2181

"Tail-Mounted Engine Architecture and Design for the Subsonic Single Aft Engine Electrofan Aircraft," Mirhashemi et al., AIAA 2022-2182

"Electrical System Trade Study for SUSAN Electrofan Concept Vehicle," Haglage et al., AIAA 2022-2183

"Thermal Management System Trade Study for SUSAN Electrofan Aircraft," Heersema et al., AIAA 2022-2302

"A Design Exploration of Natural Laminar Flow Applications for the SUSAN Electrofan Concept," Lynde et al., AIAA 2022-2303

"High-Fidelity Aerodynamic Analysis and Optimization of the SUSAN Electrofan Concept," Machado et al., AIAA 2022-2304

"A Conceptual Design of Propulsors for the SUSAN Electro-fan Aircraft," Lee et al., AIAA 2022-2305

"Implementation Approach for an Electrified Aircraft Concept Vehicle in a Research Flight Simulator," Litt et al., AIAA 2022-2306

Selected Modeling & Simulation Presentations

Conceptual Exploration of Aircraft Configurations (AIAA 2022-2181)

Timothy Chau, Gaetan Kenway, and Cetin Kiris
NASA Ames Research Center

High-Fidelity Aerodynamic Analysis of Propulsion and Airframe Integration Technologies (AIAA 2022-2304)

Leonardo Machado, Jared Duensing, Timothy Chau, Gaetan Kenway, and Cetin Kiris
NASA Ames Research Center

High-Fidelity Design and Analysis of Propulsion Systems (AIAA 2022-2305)

Byung Joon Lee and May-Fun Liou
NASA Glenn Research Center

Design Exploration of Natural Laminar Flow Wings (AIAA 2022-2303)

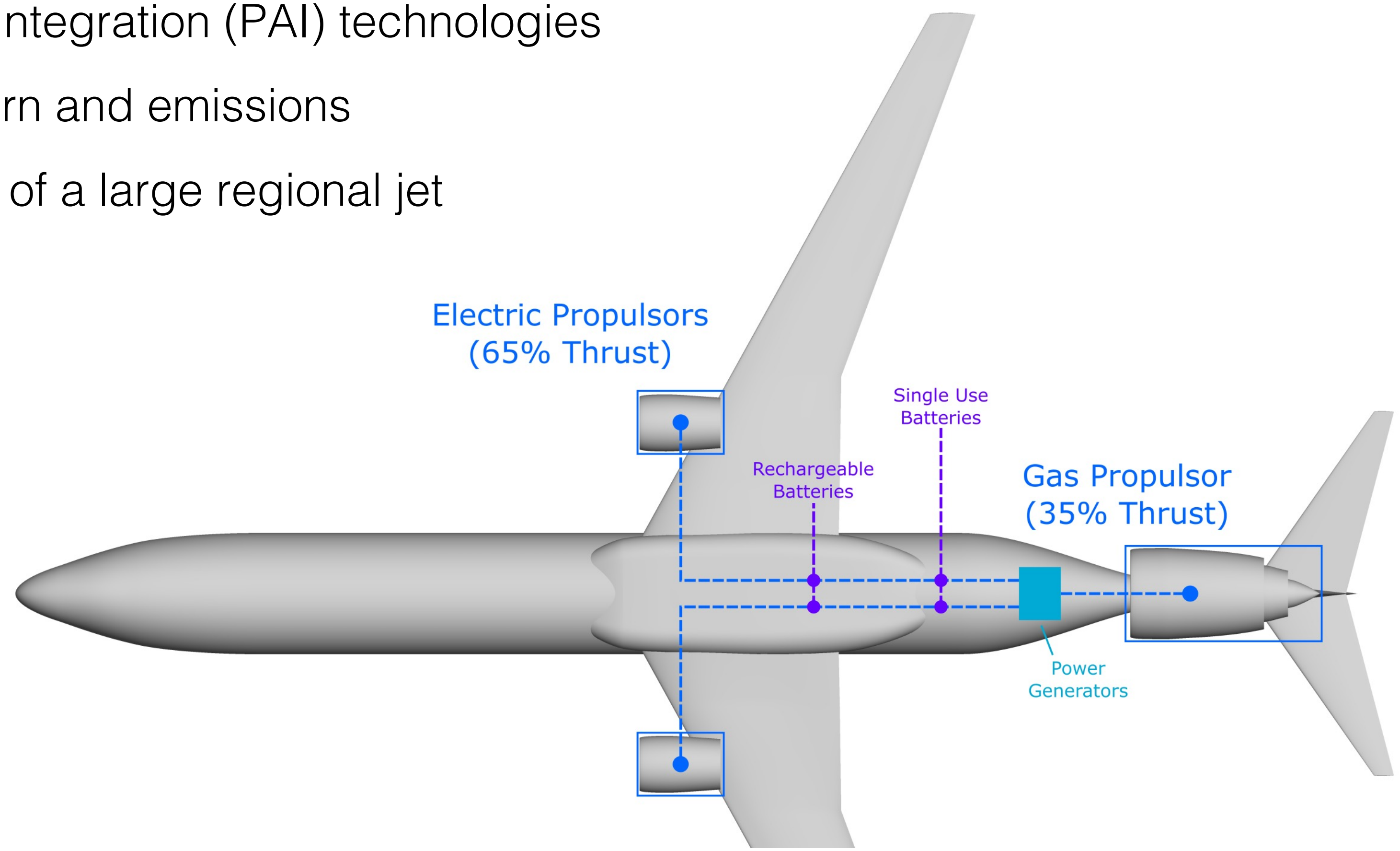
Michelle Lynde, Richard Campbell, and Brett Hiller
NASA Langley Research Center

Conceptual Exploration of Aircraft Configurations

The SUSAN Electrofan

- Transport category aircraft that uses a 20 MW class Electrified Aircraft Propulsion (EAP) system with advanced Propulsion and Airframe Integration (PAI) technologies
  - Significant reductions in fuel burn and emissions
  - Retains size, speed, and range of a large regional jet

Specifications	
Class	Regional
Capacity	180 PAX
Mach	0.785
Altitude	37,000 ft
Design Range	2,500 nmi
Economy Range	750 nmi



Schematic with hybrid electric propulsion system architecture on a generic aircraft configuration.

Which aircraft configuration should we use with this hybrid electric propulsion system architecture?

Objectives

- To explore the aircraft configuration trade space
- To provide low-order estimates of aircraft performance to help guide the evolution of the concept
- Evaluations are not final assessments; they contribute to discussions that include considerations toward technical feasibility and certifiability

Design and analysis will be performed through the application of a conceptual multidisciplinary design and analysis framework.

Design Requirements and Assumptions

Mission Requirements

Parameter	Design Mission	Economy Mission
Range [nmi]	2,500	750
Payload [lb]	36,450	36,450
Mach number	0.785	0.785
Altitude [ft]	37,000	37,000

90% load factor, 162 PAX @ 225 lb each

Assumptions

- No trades with propulsion system sizing
- No trades with power system sizing
- No integrations effects
  - No boundary-layer ingestion benefits
  - No aero-propulsive coupling
  - No structural integration penalties

Conceptual Design Environment

Faber

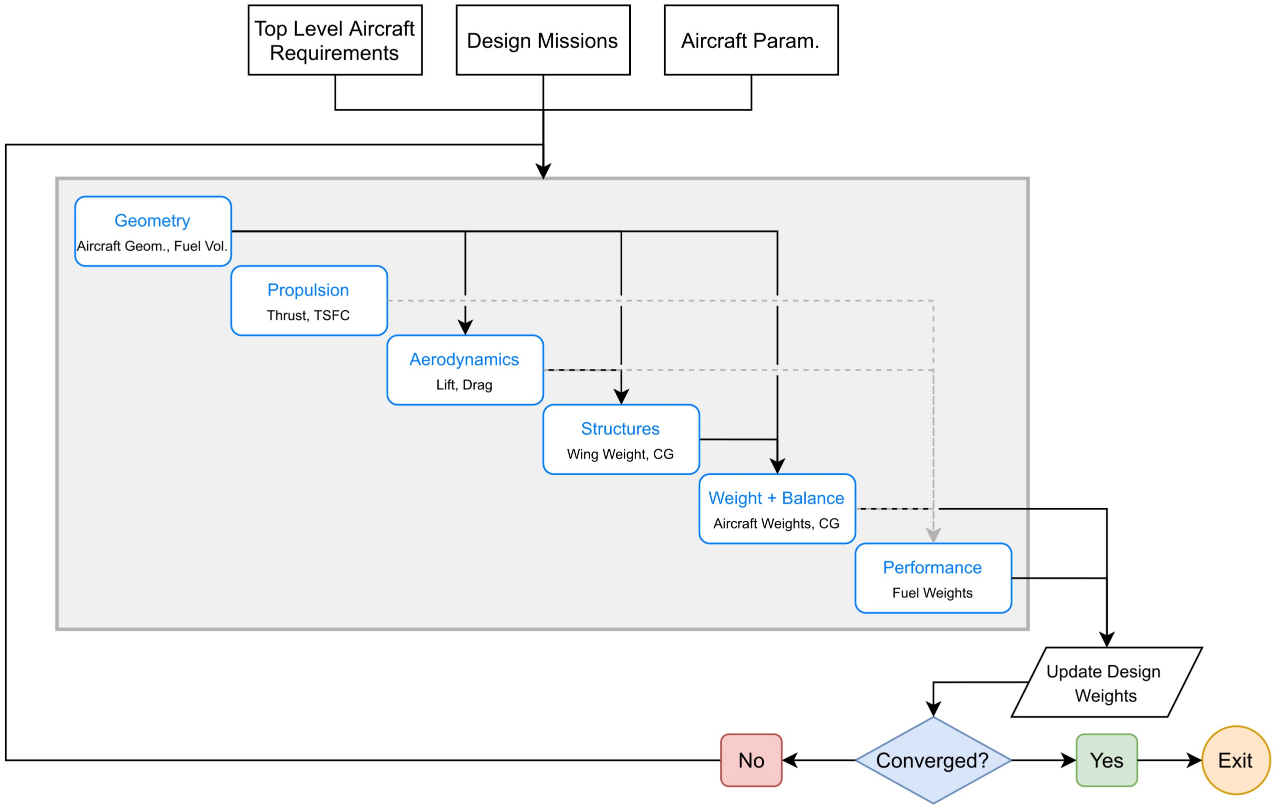
- Low-order multidisciplinary design and analysis framework
- Sizing of aircraft components and subsystems
- Disciplinary analyses

NPSS and WATE++

- Low-order propulsion models
- Engine decks

Outputs

- Design weights
- Mission fuel
- Aerodynamics, weight, propulsion



Faber sizing and analysis routine.

Propulsion Systems (NPSS, WATE++)

Parameter	Ducted Turbofan + Counter-Rot. Propfans	Open Rotor + Counter-Rot. Propfans	Ducted GTF + Distrib. Ducted Fans
Dry weight [lb]	8,953	9,264	7,161
Rotor weight [lb]	0	2,350	0
Nacelle weight [lb]	641	489	654
Aft fuse. propulsor weight [lb]	9,594	12,103	8,817
Wing propulsor weight [lb]	5,056	5,056	5,040
Thrust available (SLS) [lb]	72,222	74,433	54,305
Thrust available (TOC) [lb]	11,500	11,500	11,500
Power available (SLS) [hp]	37,166	36,770	26,314
Power available (TOC) [hp]	14,032	13,000	13,469
TSFC (SOC) [lb]	0.500	0.453	0.440

Sizing Requirements

- Thrust required @ Takeoff (TO) = 54,000 lb
- Thrust required @ Top-of-climb (TOC) = 11,500 lb
- Power required @ TO = 26,820 hp (20 MW)
- Power required @ TOC = 13,410 hp (10 MW)

Mirhashemi et al., "Tail-Mounted Engine Architecture and Design for the Subsonic Single Aft Engine Electrofan Aircraft," *AIAA SciTech 2022*

Power Systems and Batteries

- Power systems weight includes:
  - Generators
  - Converters
  - Cables
  - Thermal management systems
- Batteries weight includes:
  - Rechargeable batteries
  - Single use batteries
    - Sized based on ETOPS-like requirement

EAP System Weights	
Power systems [lb]	10,000
Batteries [lb]	9,000
Total [lb]	19,000

Weight contributions from the power systems and batteries are assumed to be constant for each aircraft configuration.

SUSAN Electrofan Variant 1

Main Drivers

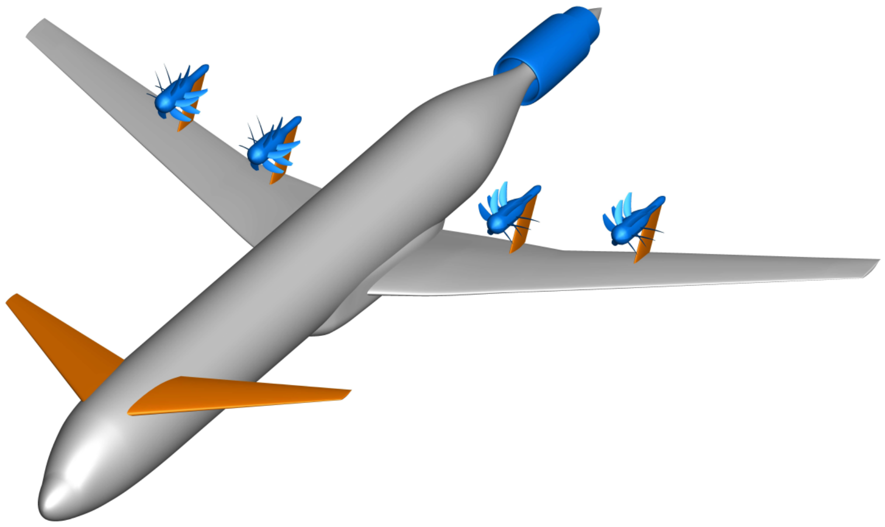
- To minimize inlet distortion experienced by aft fuselage propulsor through a tailless concept

Design Features

- Gas ducted turbofan tail cone thruster
- Electric counter-rotating propfans and control fins (4x)
  - Differential thrust and thrust vectoring for directional control
- Canards for longitudinal control

Design Challenges

- No directional stability
- Excessive dependence on active control
- Complex control system



Parameter	B737-800	SUSAN V0	Δ [%]
Max Ramp Weight [lb]	175,020	181,210	+3.5
Weight (SOC) [lb]	141,850	160,290	+13.0
Drag (SOC) [lb]	8,738	8,750	+0.1
TSFC (SOC) [lbf/lb/hr]	0.621	0.500	-19.5
Econ. Block Fuel [lb]	10,680	8,843	-17.2

SUSAN Electrofan Variant 2

Main Drivers

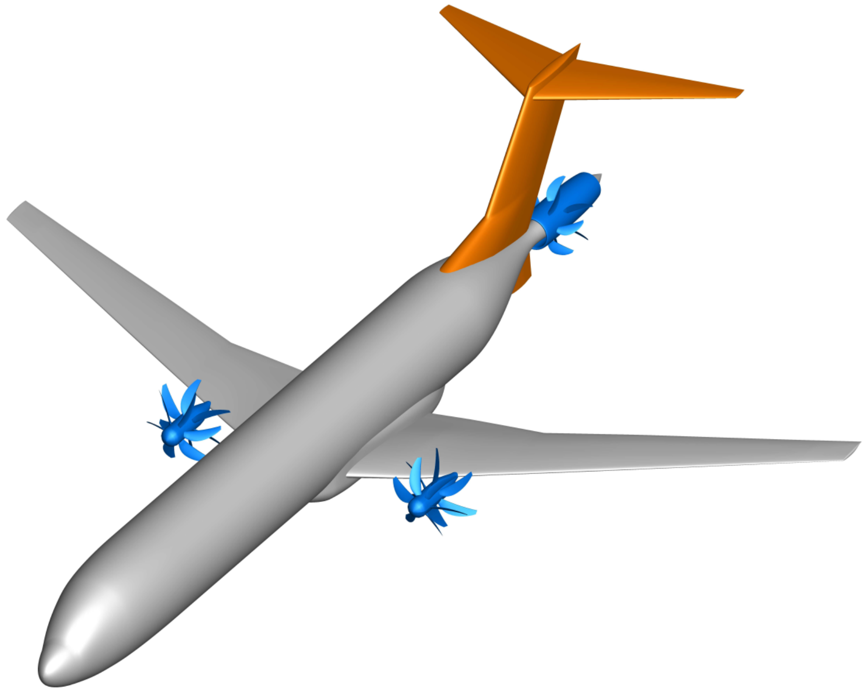
- Return to a tailed configuration
- Investigate open rotor technology

Design Features

- Gas open rotor tail cone thruster
- Electric front-of-wing counter-rotating propfans (2x)
- T-tail configuration
- Ventral fin for tail strike protection

Design Challenges

- Tail strike
- Rotor blade clearance
- Risk of damage from rotor blade off
- Noise



Parameter	B737-800	SUSAN V1	Δ [%]
Max Ramp Weight [lb]	175,020	178,505	+2.0
Weight (SOC) [lb]	141,850	158,730	+11.9
Drag (SOC) [lb]	8,738	8,290	-5.1
TSFC (SOC) [lbf/lb/hr]	0.621	0.453	-27.1
Econ. Block Fuel [lb]	10,680	8,149	-23.7

SUSAN Electrofan Variant 3

Main Drivers

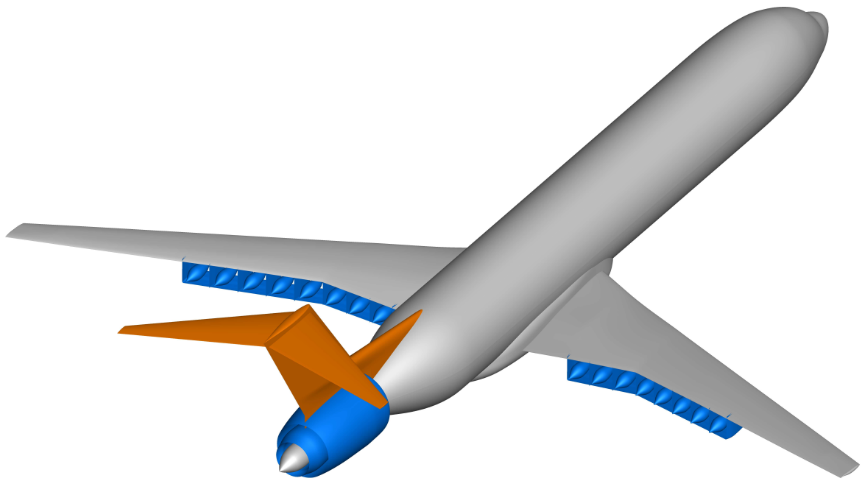
- Investigate distributed propulsion technology
- Reduce noise

Design Features

- Gas ducted geared turbofan tail cone thruster
- Electric distributed ducted fans (16x)
- T-tail configuration

Design Challenges

- Inlet distortion
- Strong aero-propulsive coupling



Parameter	B737-800	SUSAN V1	Δ [%]
Max Ramp Weight [lb]	175,020	173,260	-1.0
Weight (SOC) [lb]	141,850	153,960	+8.5
Drag (SOC) [lb]	8,738	8,080	-7.5
TSFC (SOC) [lbf/lb/hr]	0.621	0.440	-29.1
Econ. Block Fuel [lb]	10,680	7,813	-26.8

Summary and Future Work

Summary

- Explored the aircraft configuration trade space through low-order multidisciplinary design and analysis
- Considered several combinations of airframe and propulsion system configurations
- Results indicate that even with a subset of the effects and technologies included, the SUSAN Electrofan concept has the potential to provide significant improvements to fuel efficiency

Future Work

- Introduce impact of higher-order effects
  - e.g. Boundary-layer ingestion, aero-propulsive coupling, structural integration
- Incorporate trades with propulsion and power
- Introduce benefits from other advanced technologies such as natural-laminar-flow wings

High-Fidelity Aerodynamic Analysis of Propulsion and Airframe Integration Technologies

Objectives

- **High-fidelity aerodynamic analysis of the SUSAN Electrofan concept**
- **Two focus areas currently under investigation:**
  - Tail Cone Thruster
  - Distributed Electric Propulsion System
- **Launch, Ascent, and Vehicle Aerodynamics (LAVA) framework[1]**
  - Steady state compressible Reynolds-Averaged Navier-Stokes (RANS) solver
  - Structured curvilinear overset mesh paradigm
  - Propulsion modelled through actuator zones
- **Aerodynamic Shape Optimization using MACH software[2]**

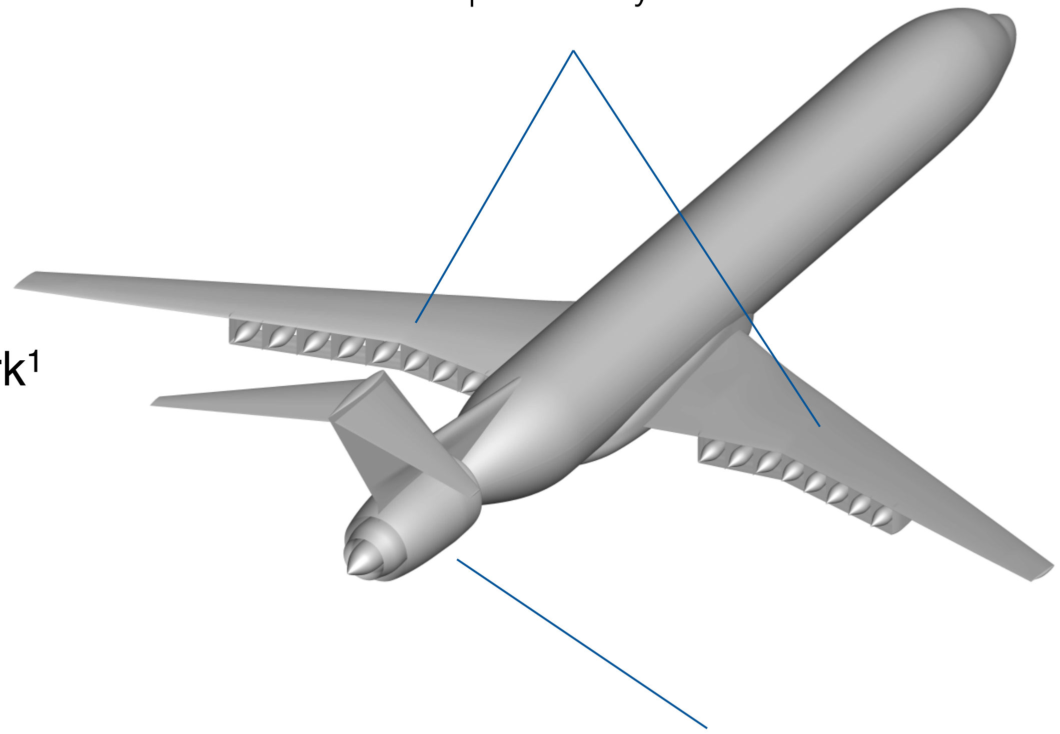


Figure. SUSAN Electrofan Concept

[1]Kiris, C., Housman, J., Barad, M., Brehm, C., Sozer, E.,and Moini-Yekta, S., "Computational framework for Launch, Ascent, and Vehicle Aerodynamics (LAVA)," Aerospace Science and Technology, Vol. 55, 2016, pp. 189–219
[2]Kenway, G. K. W., Kennedy, G. J., and Martins, J. R. R. A., "Scalable Parallel Approach for High-Fidelity Steady- State Aeroelastic Analysis and Adjoint Derivative Computations," AIAA Journal, Vol. 52, No. 5, 2014, pp. 935–951.

Tail Cone Thruster
(TCT)

Tail Cone Thruster

- Inform design sizing
  - TCT model that meets mass flow rate requirements
- Aerodynamic shape optimization
  - Modify aft fuselage geometry to reduce flow distortion

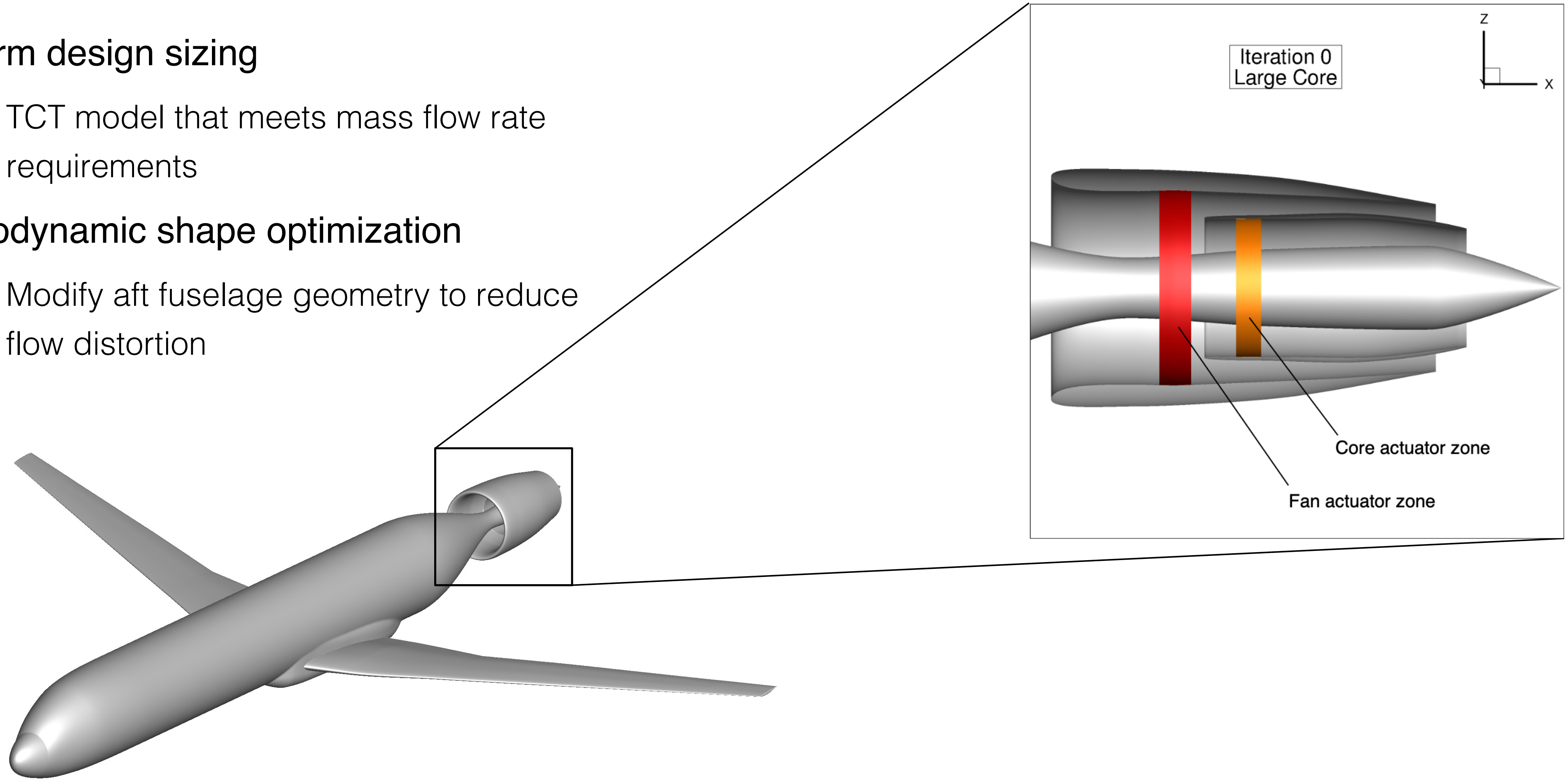


Figure. TCT Design Iteration 0

TCT: Engine Sizing

- Iteration 0
  - Evaluated mass flow sensitivity
  - Identified key flow features
  - Data used to inform inlet, core, and bypass duct sizing

- Iteration 1
  - Re-designed core and bypass ducts
  - Characterized TCT flow distortion profile
  - Inlet and outlet profiles informed detailed engine modeling

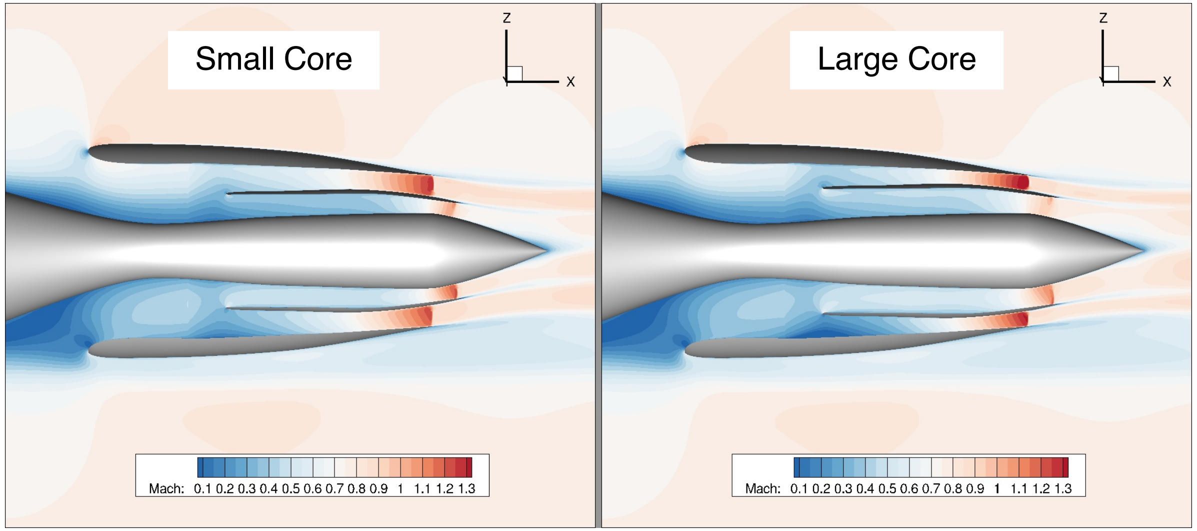


Figure. TCT Design Iteration 0

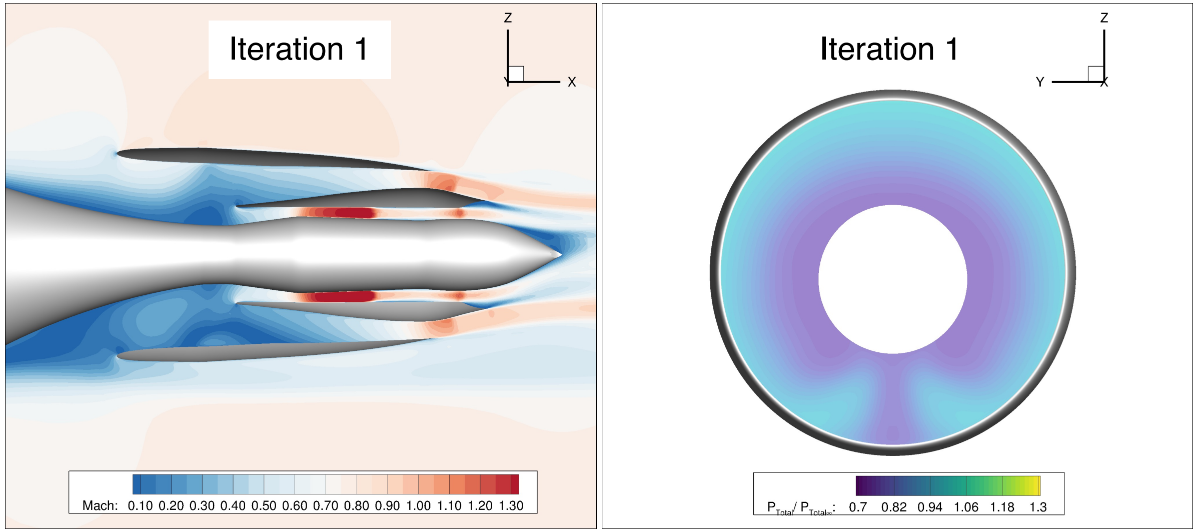


Figure. TCT Design Iteration 1

TCT: Tail Cone Optimization

- Aerodynamic shape optimization to minimize fan distortion
  - Single point unconstrained
  - Nominal cruise condition
- T-tail and Inlet Guide Vanes (IGVs) introduced once a satisfactory design was obtained
- Reduction in distortion intensity (ARP1420 metric) from 10.1% to 7.9%

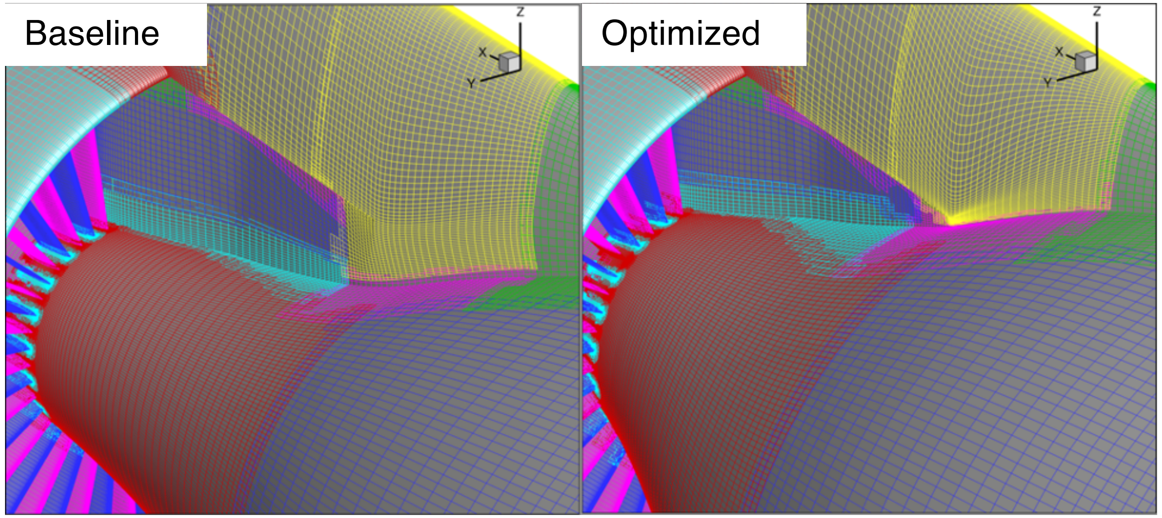


Figure. T-tail and IGV fuselage integration

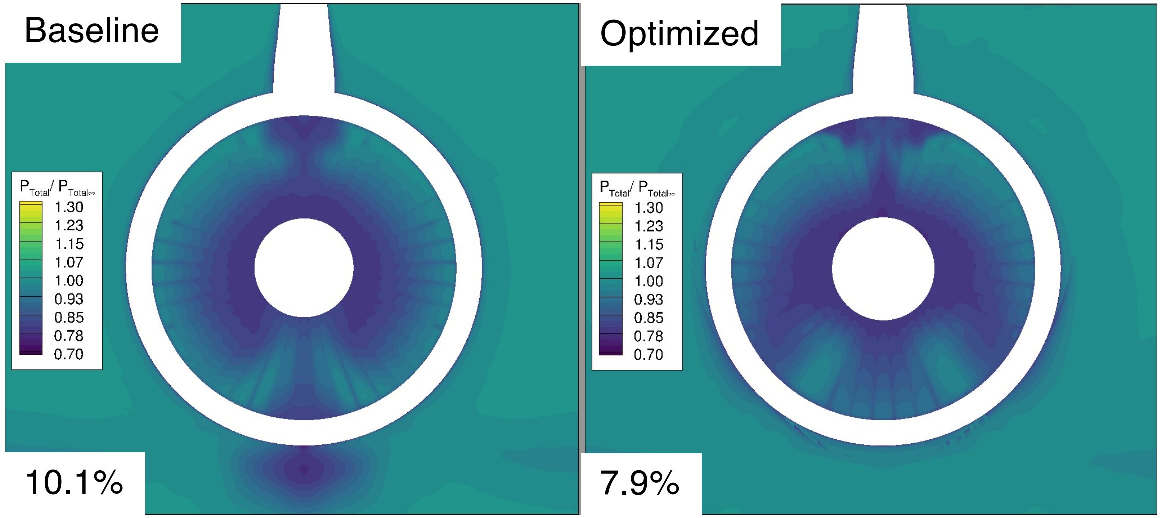


Figure. Distortion profile at TCT fan face

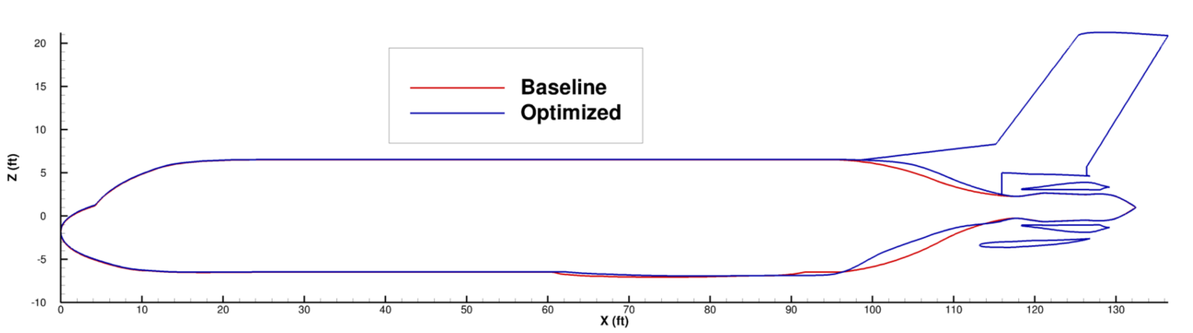


Figure. Comparison between the baseline and optimized fuselage

Distributed Electric Propulsion (DEP)

Distributed Electric Propulsion

- Development of ducted fan model
- Integration of ducted fan onto the wing
- Simplified infinite wing models used to explore design space
  - Nominal conditions (C_L=0.501, Fan pressure ratio=1.25)
  - Off Design conditions (Unpowered, +/- 10% Thrust)

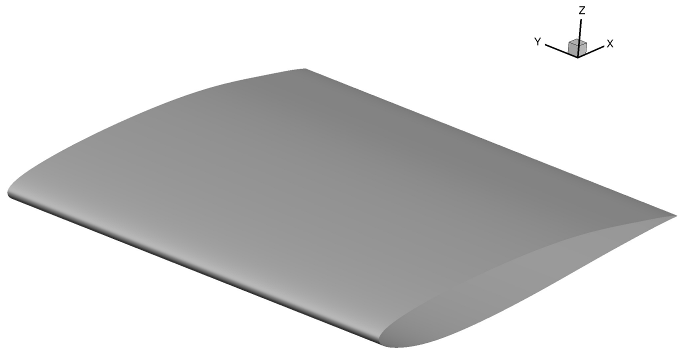


Figure. Infinite clean wing model

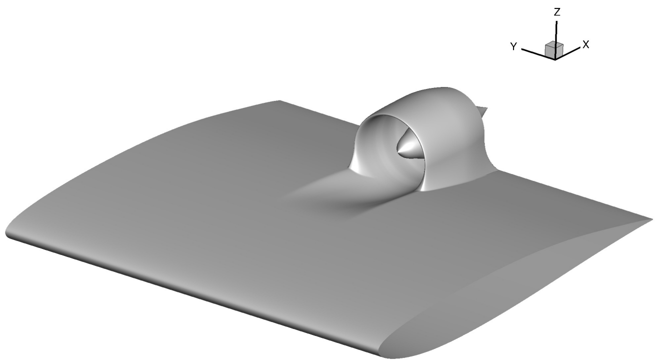


Figure. Infinite over-wing model

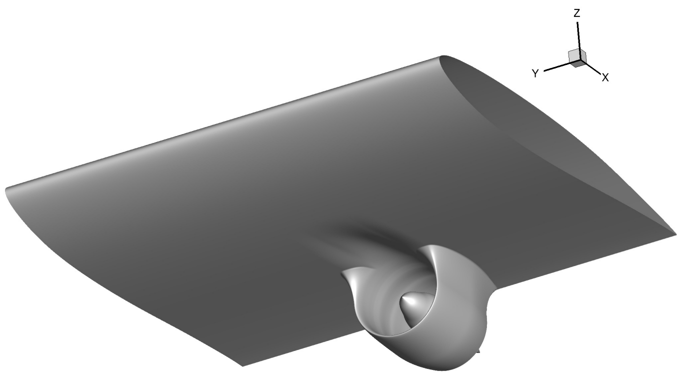


Figure. Infinite under-wing model

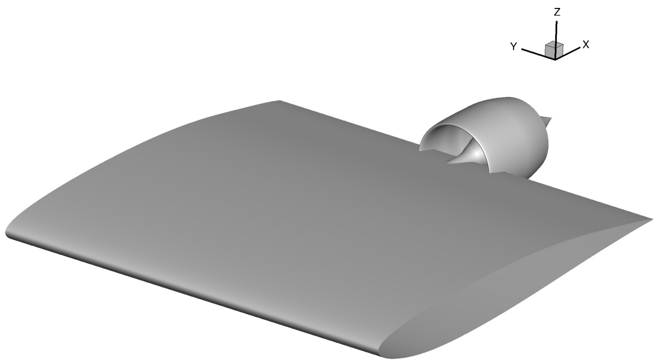


Figure. Infinite trailing edge model

DEP: Ducted Fan Sizing

- Isolated propulsor
  - Fan pressure ratio = 1.25
- Dual counter rotating fan
  - Load equally distributed
- Target mass flow rate achieved with 6% margin

	Iteration 2	Target
Fan pressure ratio	1.25	1.25
Mass flow rate [kg/s]	35.64	33.65

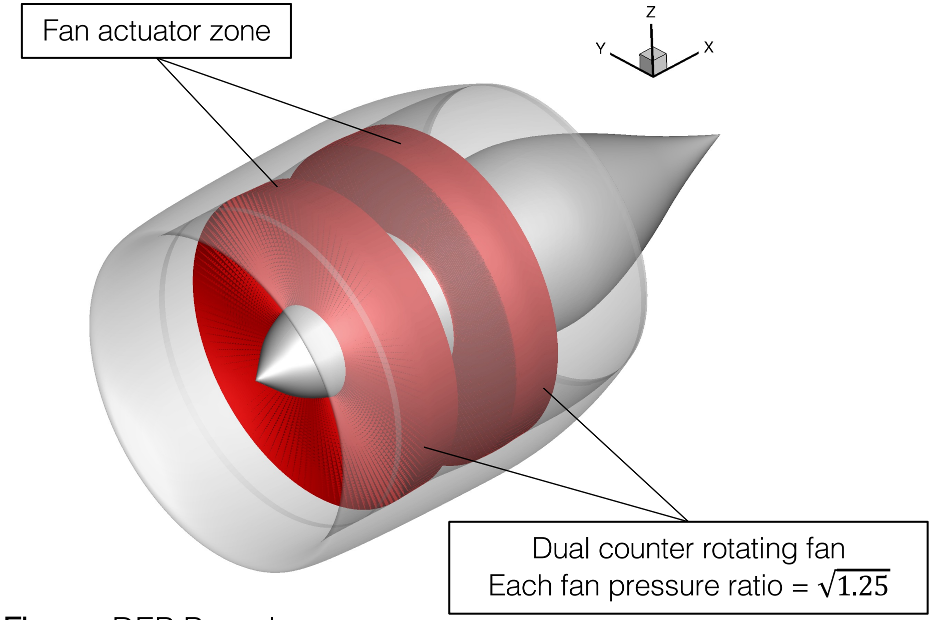
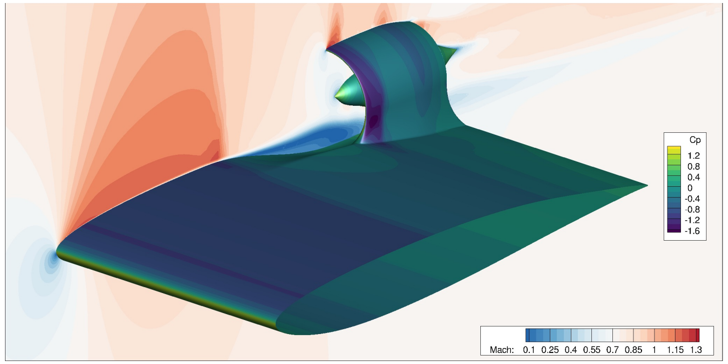


Figure. DEP Propulsor

DEP: Propulsion Airframe Integration

Over-wing



Advantages:

- Upper surface suction
- Lift enhancement with thrust

Challenges:

- Inset design
- Upper surface shock formation

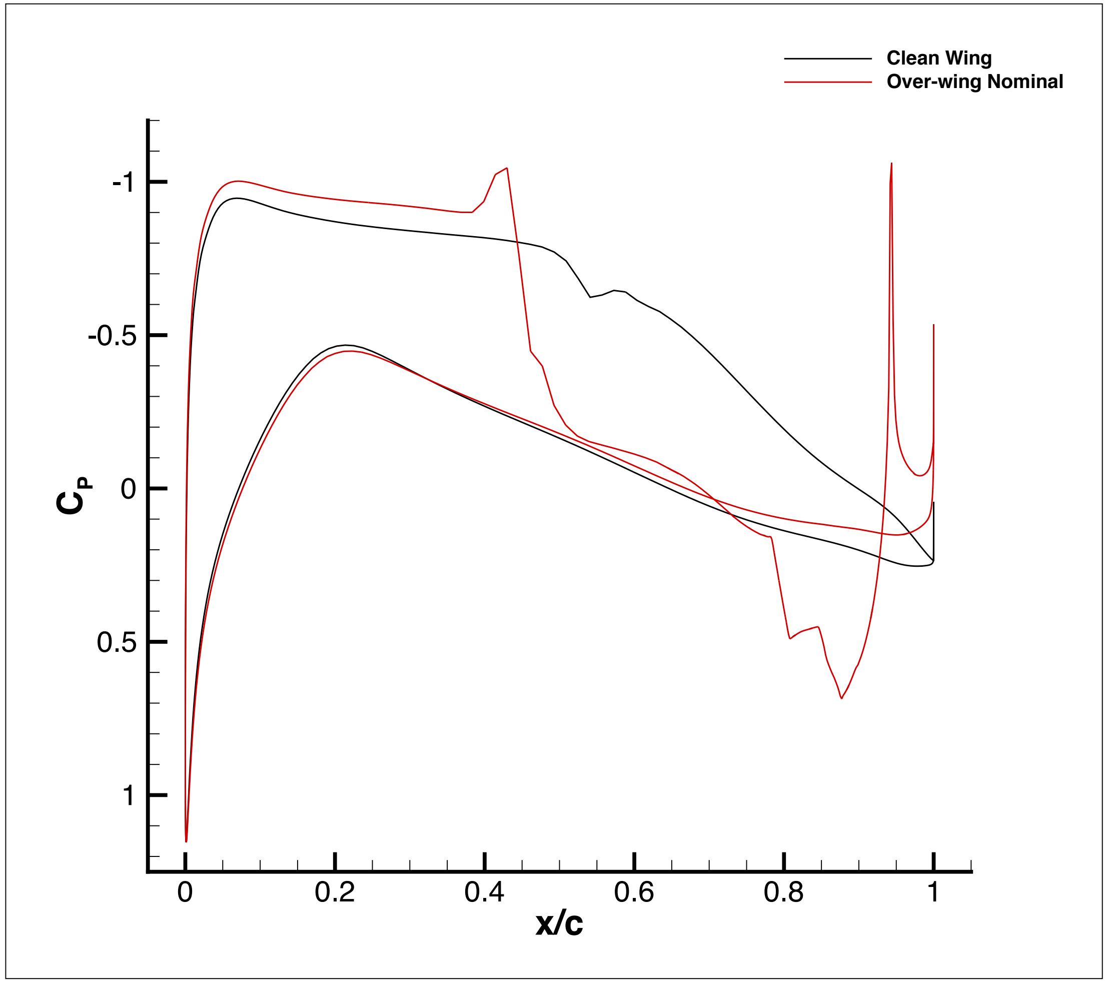
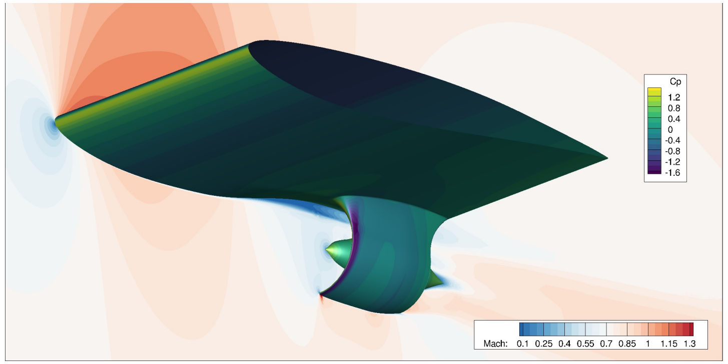


Figure. Nominal (powered) pressure distribution for over-wing configuration

DEP: Propulsion Airframe Integration

Under-wing



Advantages:

- More upper surface natural laminar flow
- Less integration penalties

Challenges:

- Lower surface suction
- Low BLI benefit

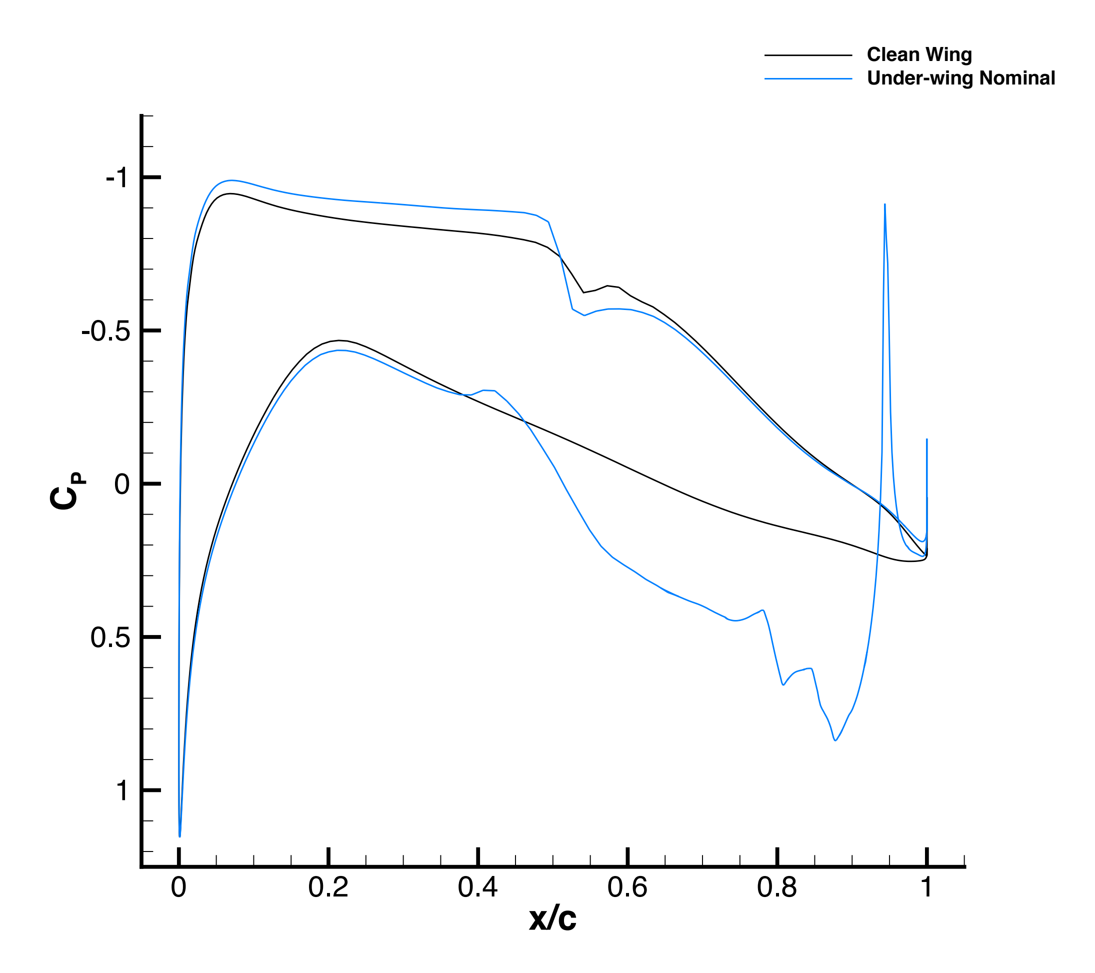
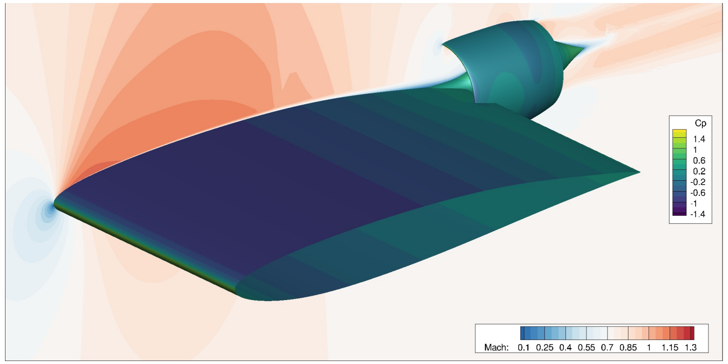


Figure. Nominal (powered) pressure distribution for under-wing configuration

DEP: Propulsion Airframe Integration

Trailing edge



Advantages:

- Lowest integration penalties
- BLI benefit

Challenges:

- Inlet distortion
- System level complexities

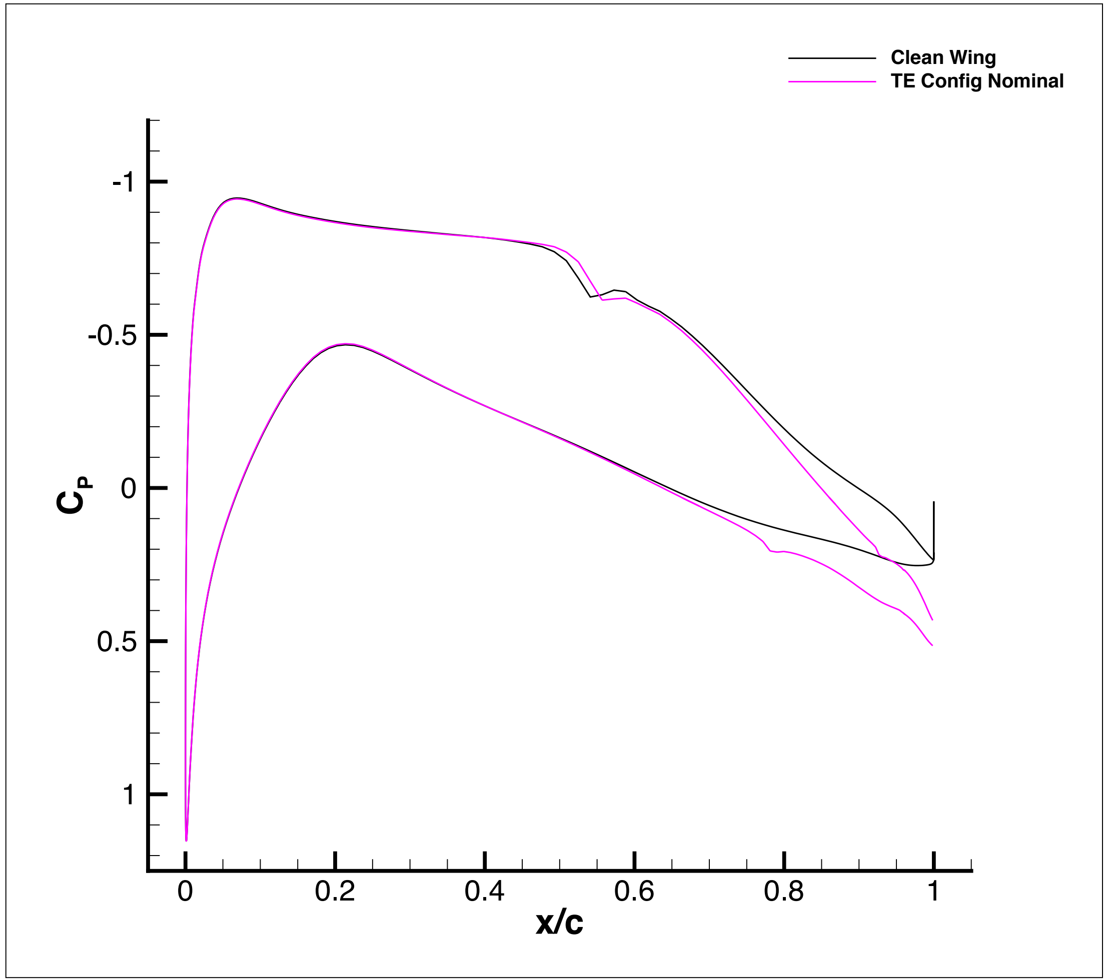


Figure. Nominal (powered) pressure distribution for trailing edge configuration

DEP: Propulsion Airframe Integration

	Clean Wing + Propulsor	Over-wing	Under-wing	TE
FPR	1.25	1.25	1.25	1.25
C_L	0.501	0.501	0.501	0.501
α [deg]	0.8599	1.3929	1.1692	0.8366
C_D [counts]	145.589	205.649	157.151	128.906

Conclusions

- High-fidelity aerodynamic analyses in support of the development of the SUSAN Electrofan
- Tail Cone Thruster:
  - Correct sizing of core and bypass ducts determined
  - Aerodynamic shape optimization tools applied
  - Distortion intensity reduced from 10.1% to 7.9%
- Distributed Electric Propulsion:
  - Developed feasible ducted fan model
  - Trade space exploration between three DEP system configurations
    - Over-wing
    - Under-wing
    - Trailing edge

High-Fidelity Design and Analysis of Propulsion Systems

Propulsion Systems I: Turboelectric Distributed Propulsors (TeDP)

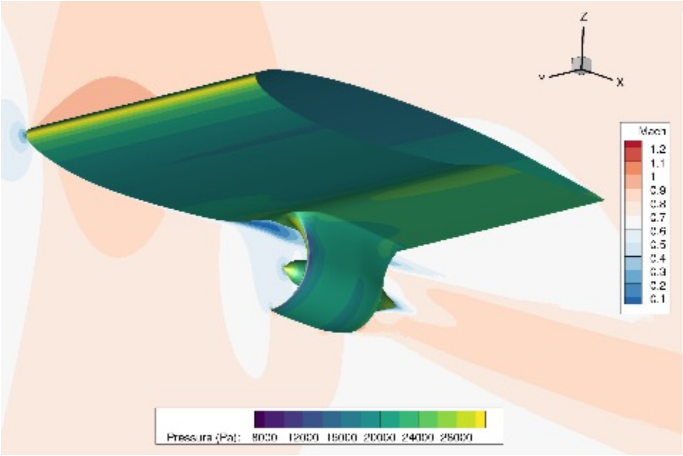
Boundary Layer Ingesting Propulsion Technology

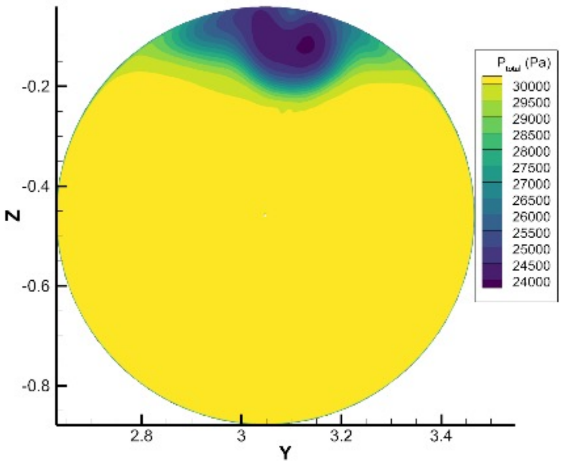
Pros

- Ingesting low momentum flow
  - Reduction of ram drag at the inlet face
  - Shaft power saving

Cons

- Distorted profile at the fan face
  - Deficiency of turbomachinery part (fan)
- Flow blockage (low momentum flow)
  - Nacelle sizing (larger capture area)





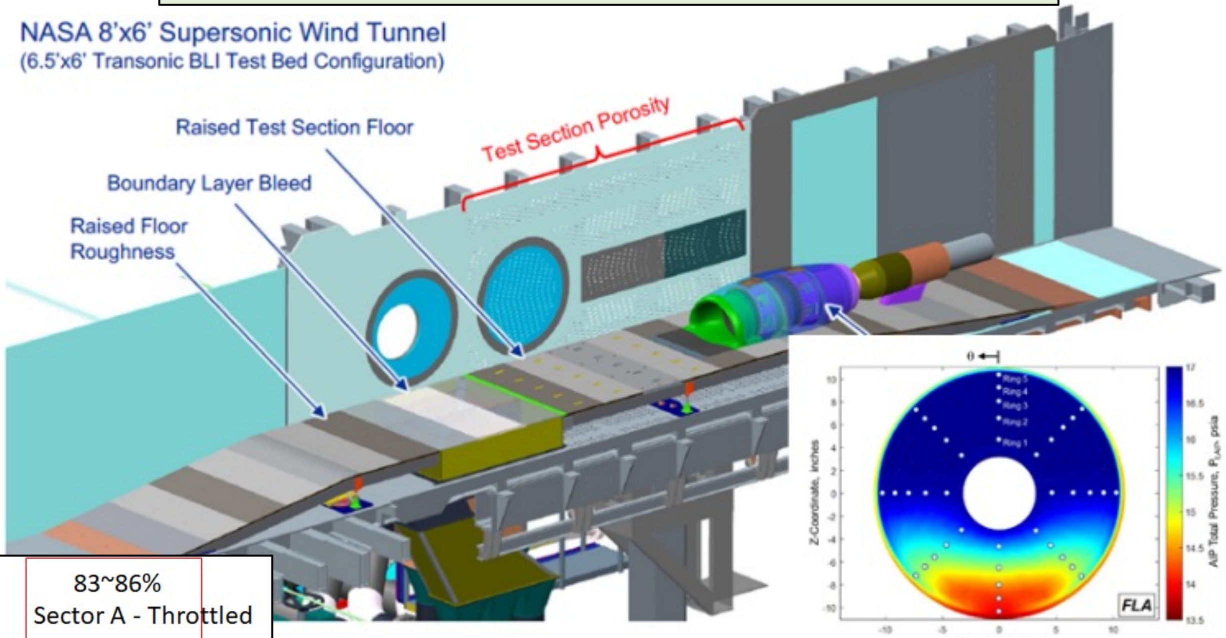
Under-wing Mounted Distributed Propulsion Systems (DeP)

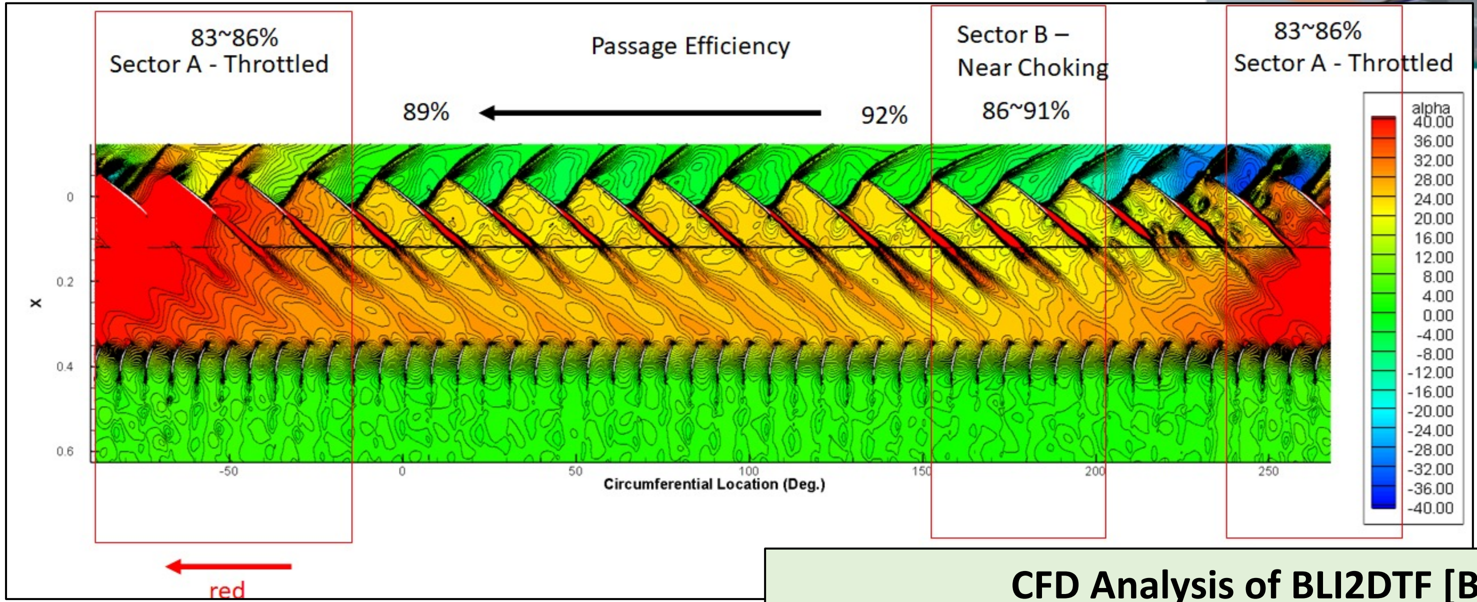
No. of Engine Units	FSPR	Installation	Fan diameter [ft]	Shape Factor (H)	Iteration No.
	1.25	Underwing	2.41	1.14	04
16	MFR [kg/sec]	Shaft Power [MW]	Thrust Generation (kN)	Power Saving (%)	Theoretical Power Saving (%)
	30.3	0.49	2.08	12.2	13.5

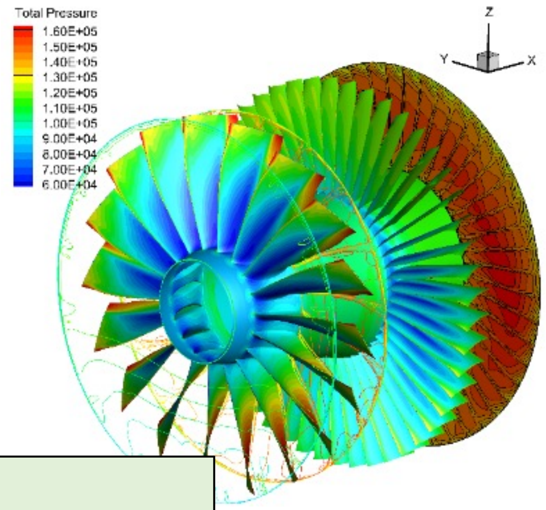
Why Distortion Tolerant Fans (DTF)?

1. Local variation of properties affects the overall performance of the rotor significantly.
   - Total pressure & temperature → mass flow rate → Incidence
2. Every passage operates in different operating conditions → efficiency penalty

BLI2DTF wind tunnel test article [D. Arend et al.]







CFD Analysis of BLI2DTF [B.Lee et al.]

Counter Rotating Fans

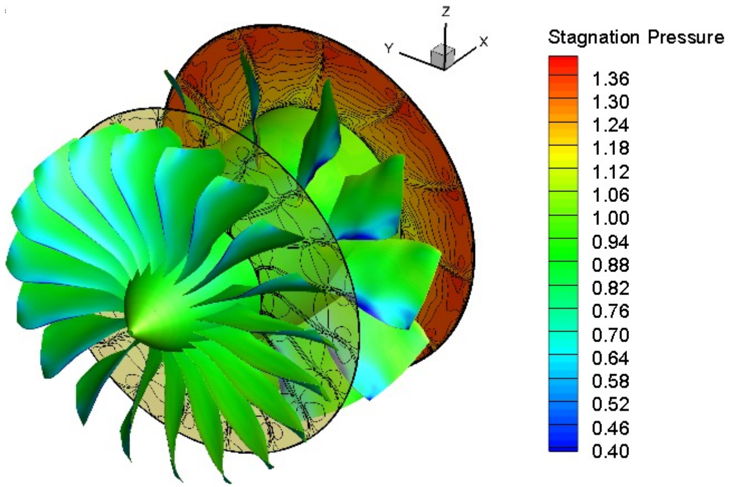
1. Counter rotating fans – Sharing loads
- Two blade rows share the load (split pressure ratio)
- Compensating each blade row's weakness
- No OGV (outlet guide vane) is needed.
2. Low rotational speed

→ less sensitivity to the incidence swing

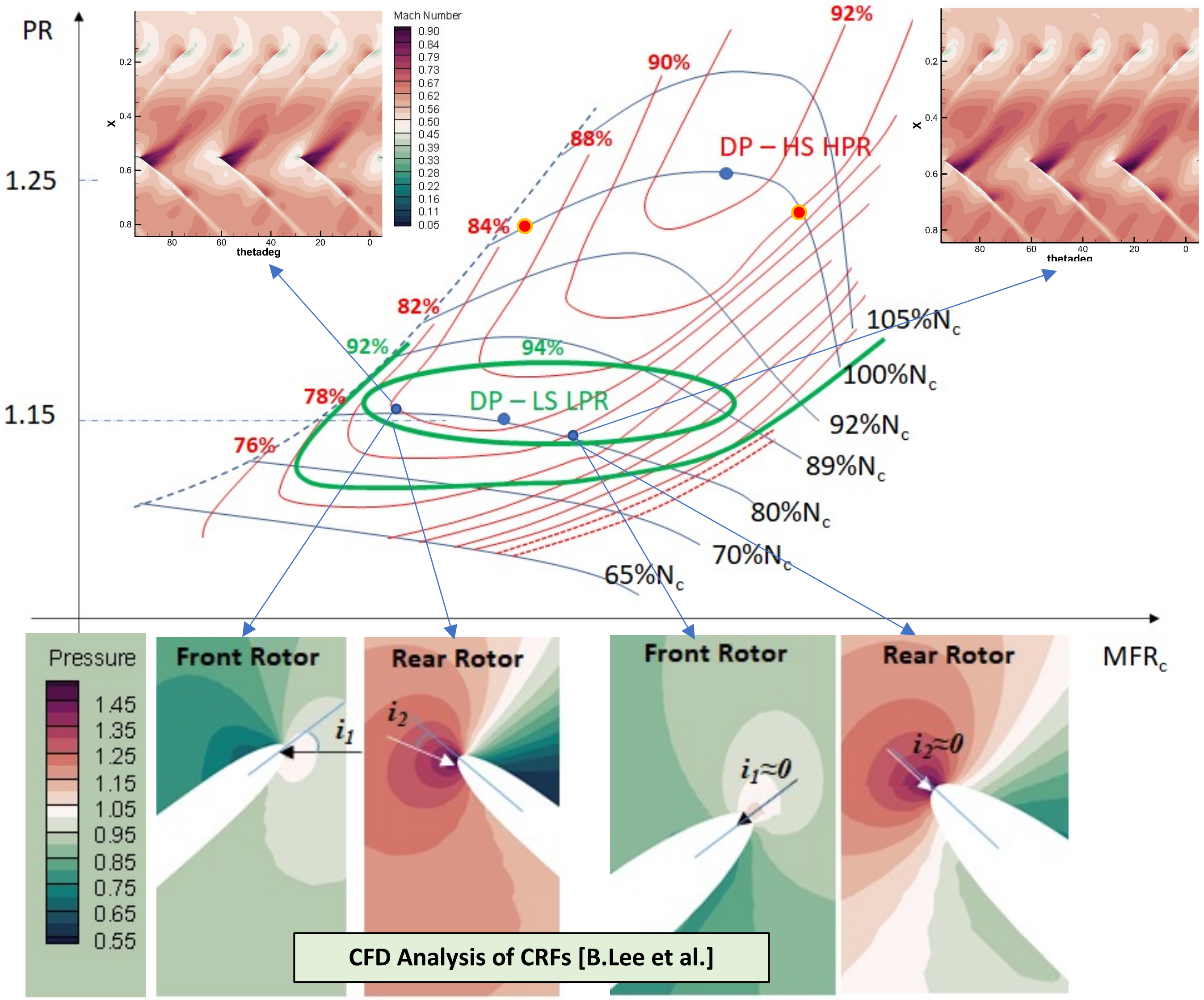
→ high tolerance to the change of the condition

3. Low pressure ratio

→ high efficiency of each blade row**



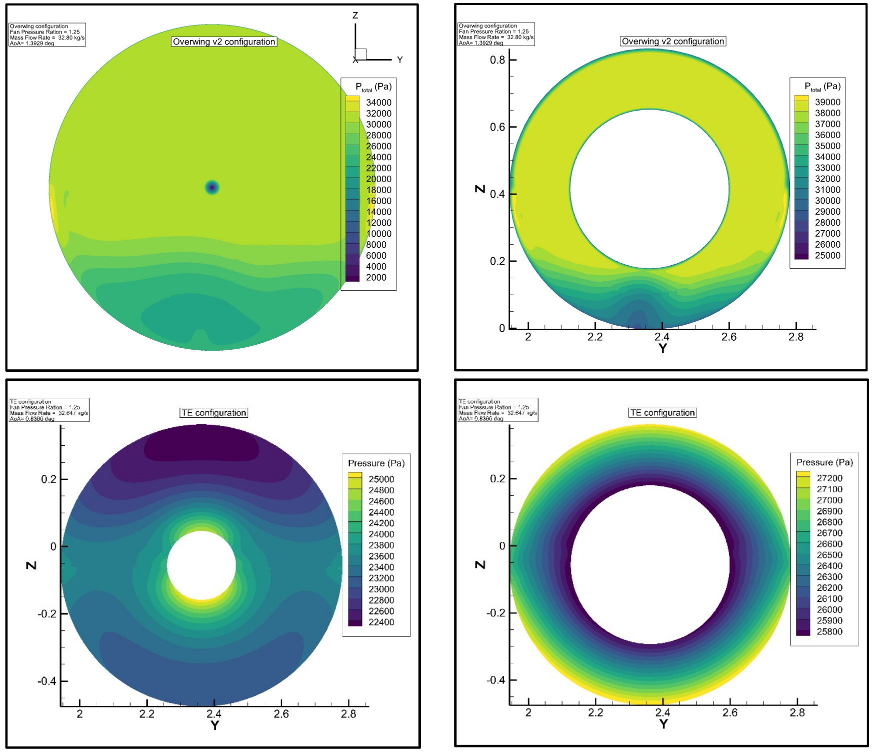
Comparison of Performance Maps of High Speed and Low Speed Rotors

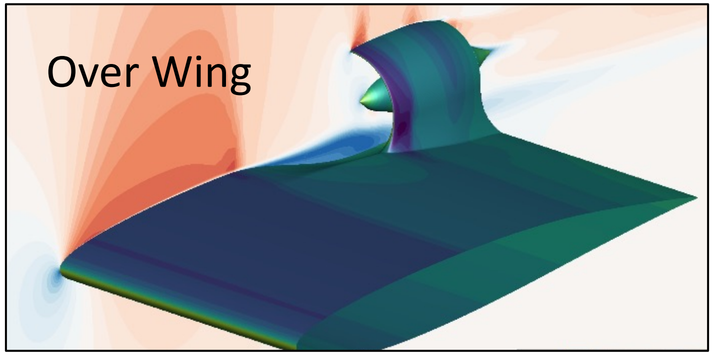


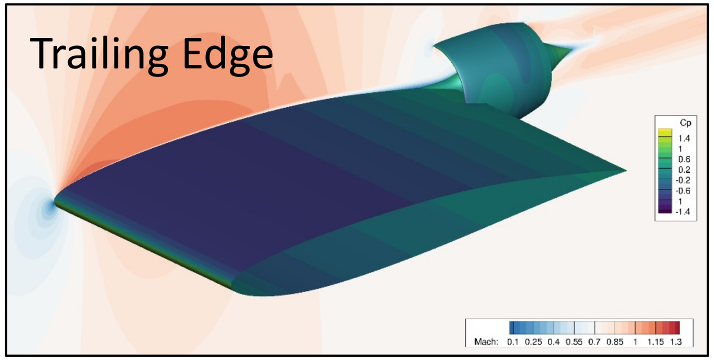
CFD Analysis of CRFs [B.Lee et al.]

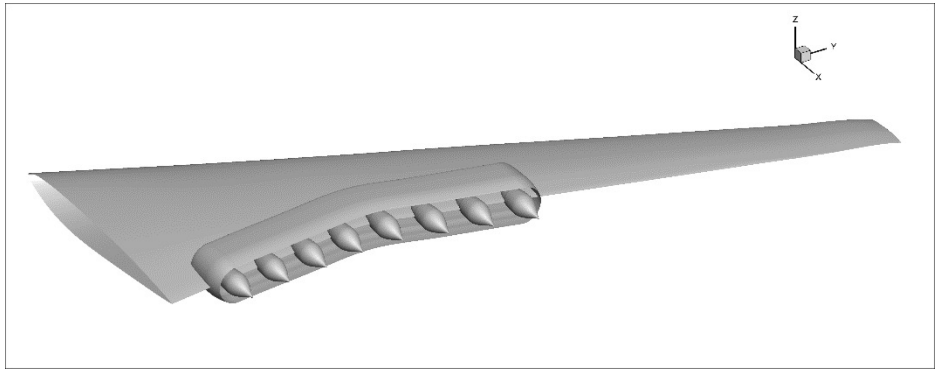
Proposal with Wing Installation

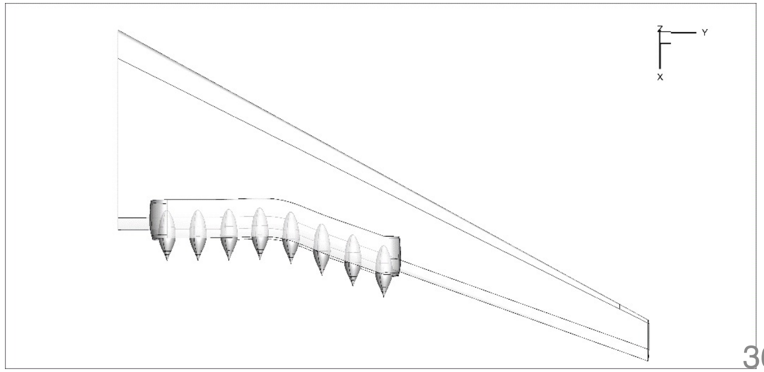
Methods	Over-wing	Trailing Edge
Shaft Power (MW)	0.41	0.46
MFR (kg/sec)	24.3	27.6
Shape Factor	1.24	1.22
FSPR	1.28	1.27
Power Saving (%)	26.9	17.4







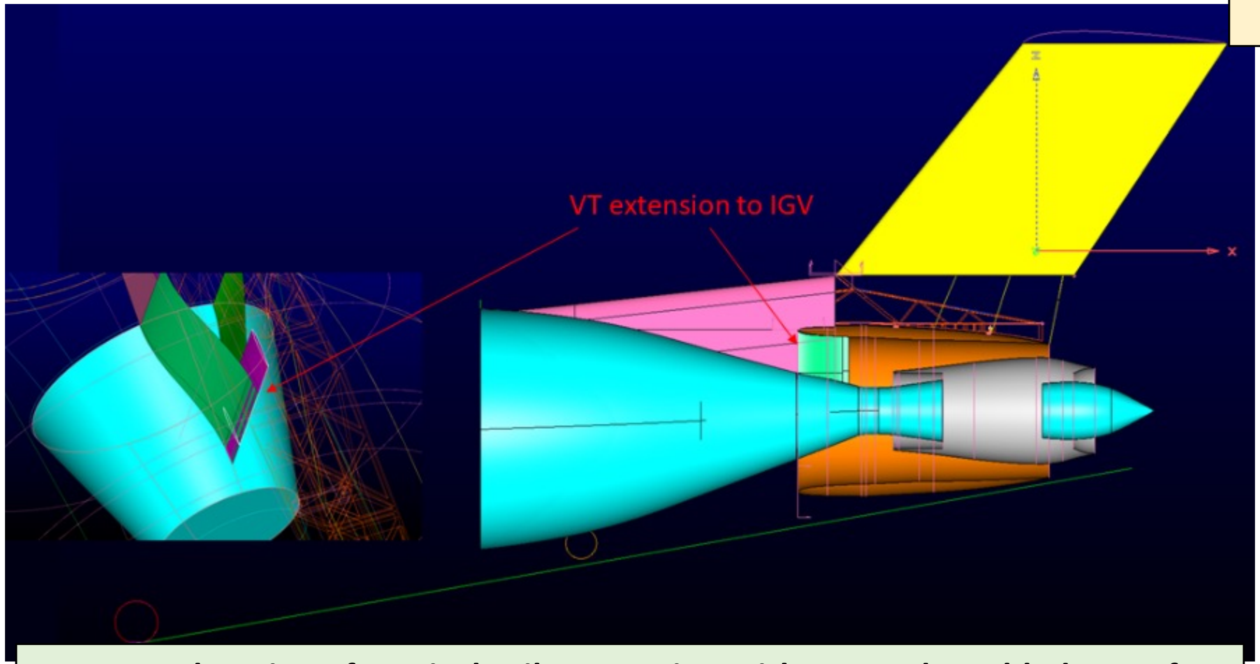




Propulsion Systems II:
Tail-Cone Thruster (TCT)

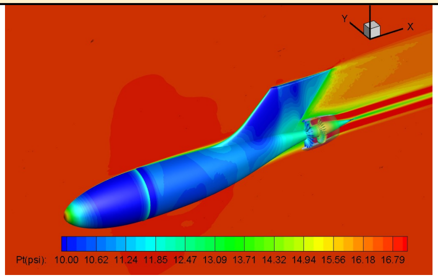
Installation of Fan Stage with VT and IGVs

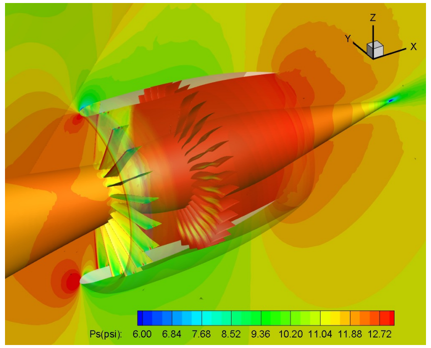
- Applying IGVs mitigates the swirl distortion caused by the ingested wake from the airframe.
- The integration of the vertical tail structurally allows Variable IGVs (vIGVs) for the active control of the incoming swirl distortion from the BLI.

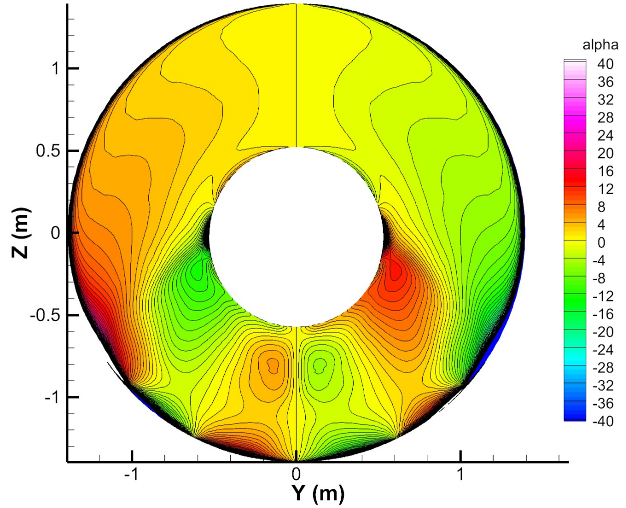


Structural Design of Vertical Tail Integration with TCT and IGV blade row for SUSAN Electrofan Full Scale Aircraft Model

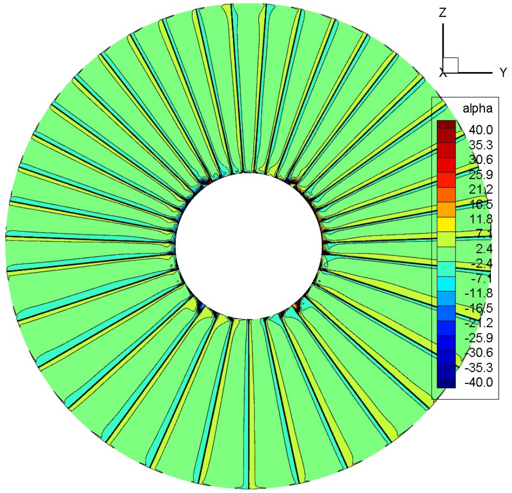
CFD Analysis of NASA's 12" TCT Model for Wind Tunnel Test







Swirl Distribution at Fan Face (without IGV)

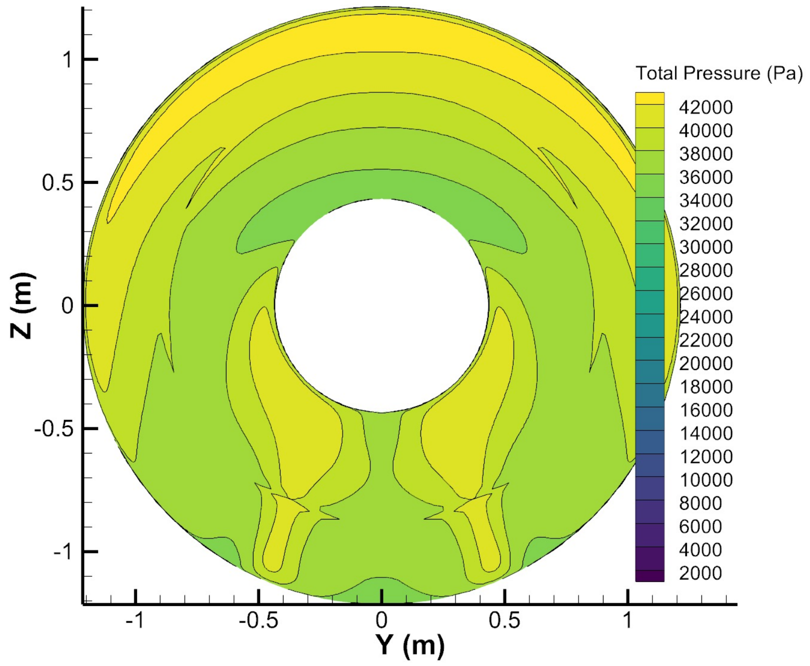


Swirl Distribution at Fan Face (with IGV)

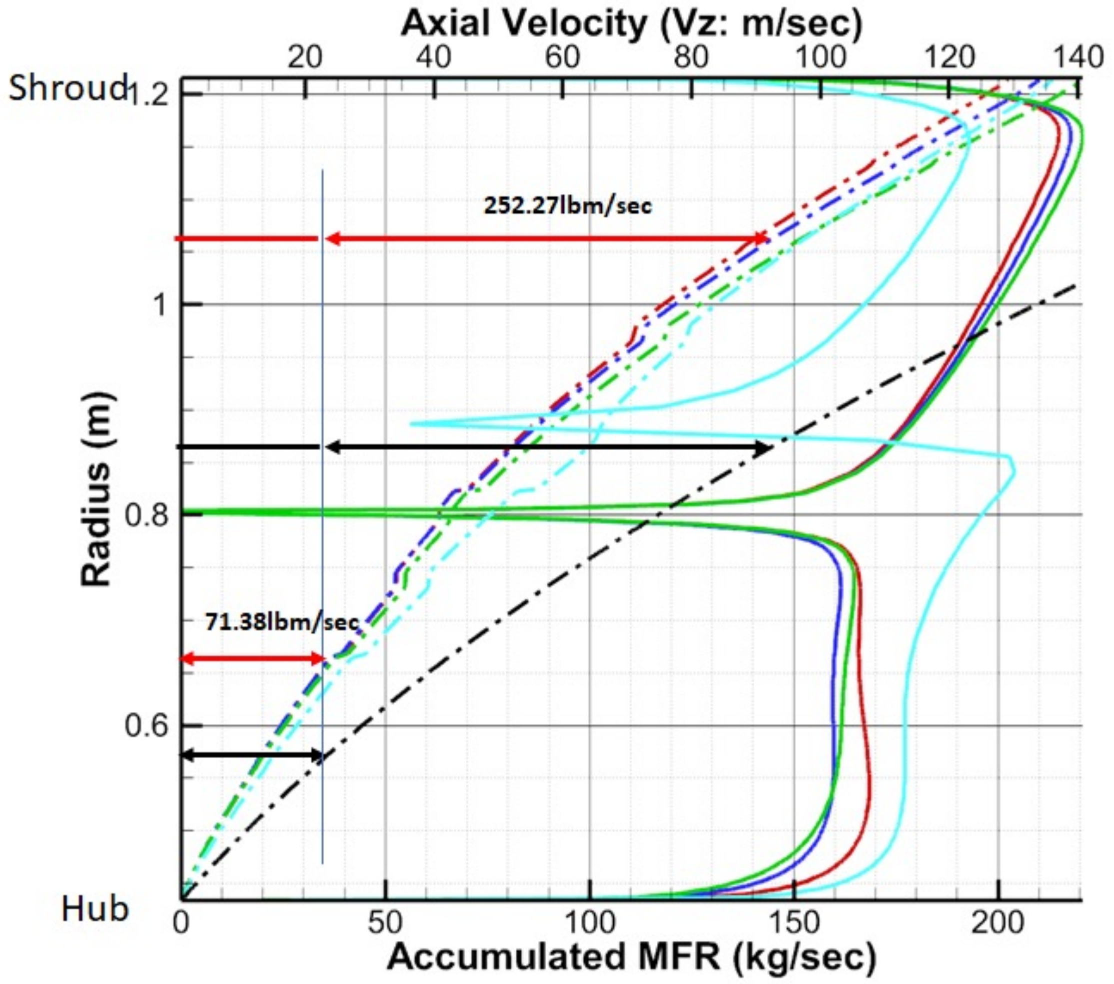
Example of Swirl Control via IGVs

Profile Split into the Bypass and Core Ducts

- The diameter of the core duct is determined to be 1.2 times larger than that of clean inlet flows.
- Core inlet profile evolves flattened shape (radially more uniform) → more favorable for the core performance.

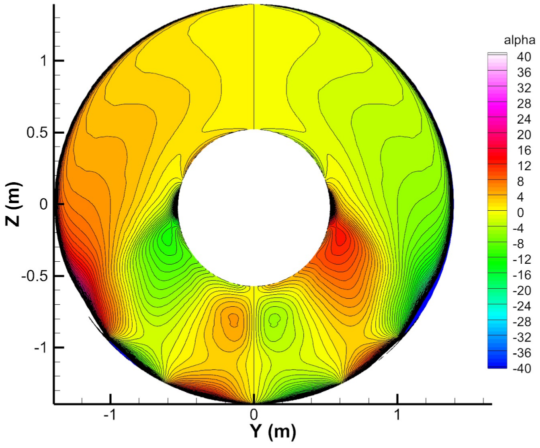


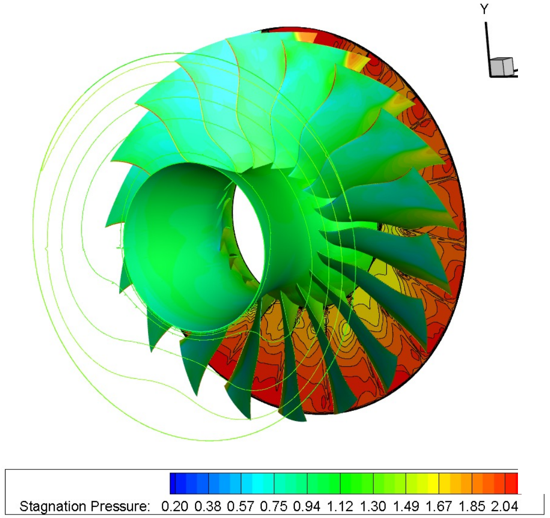
Total Pressure Profile at the Splitter Section

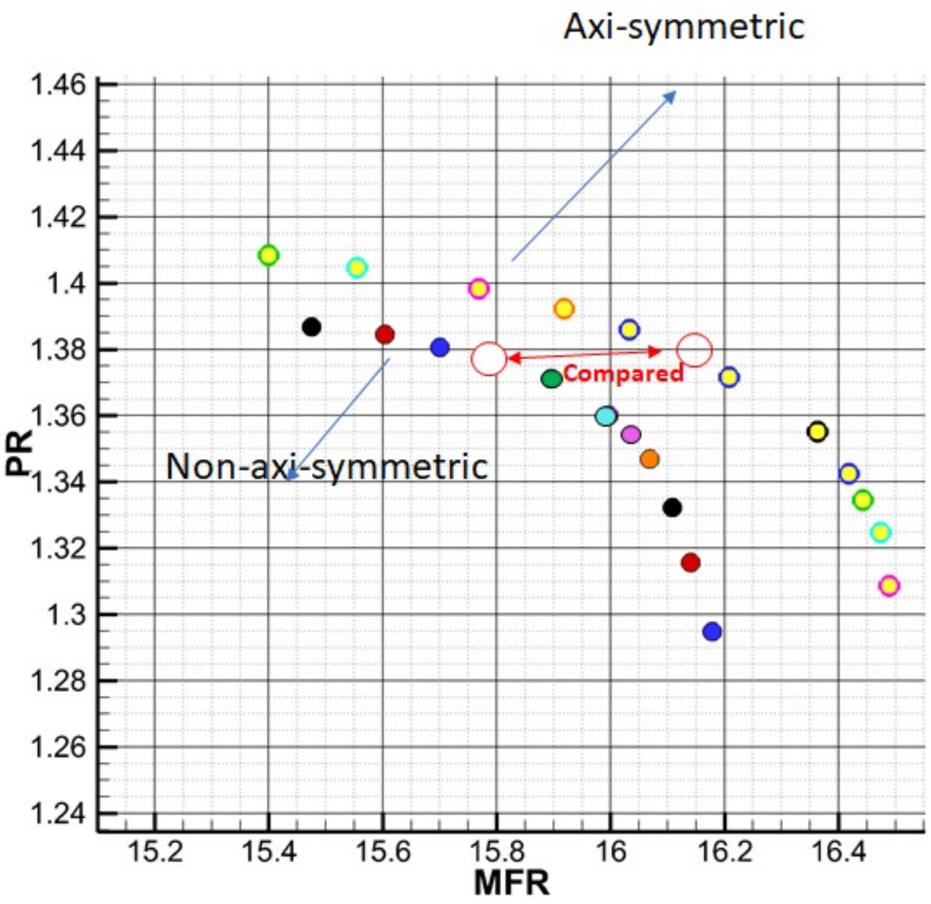


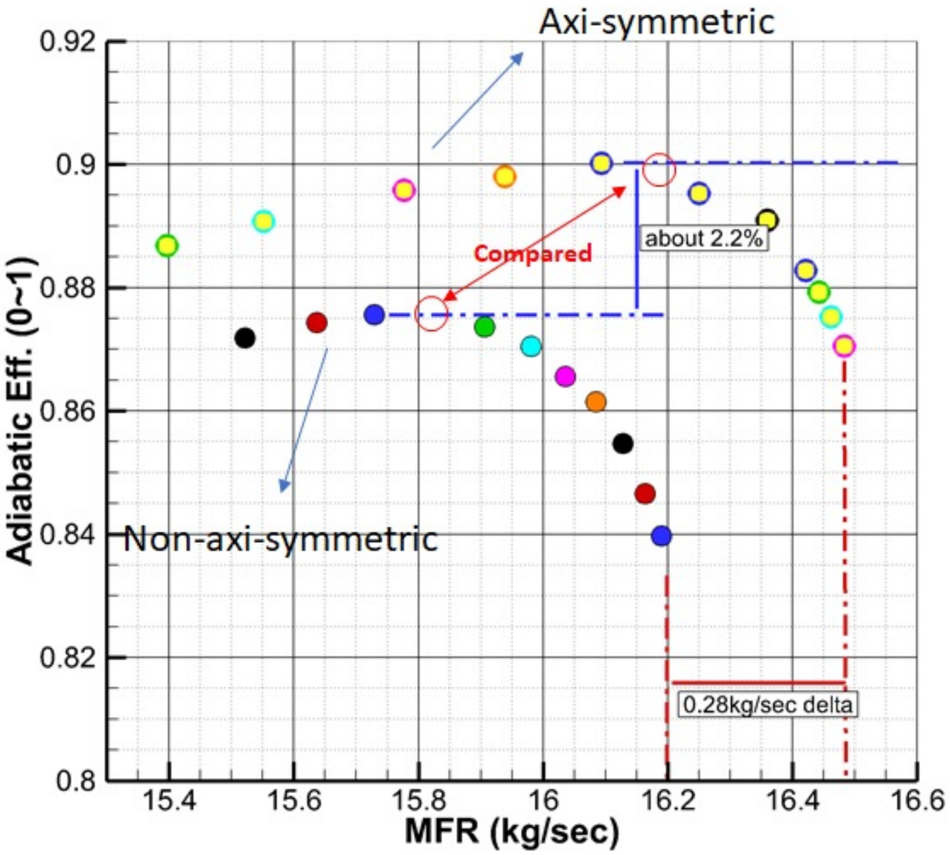
Circumferentially Averaged Mass Flow Rate and Velocity Profiles at the Core and Bypass Inlet Face

Impact of the Non-Axisymmetric Distortion (Type II)







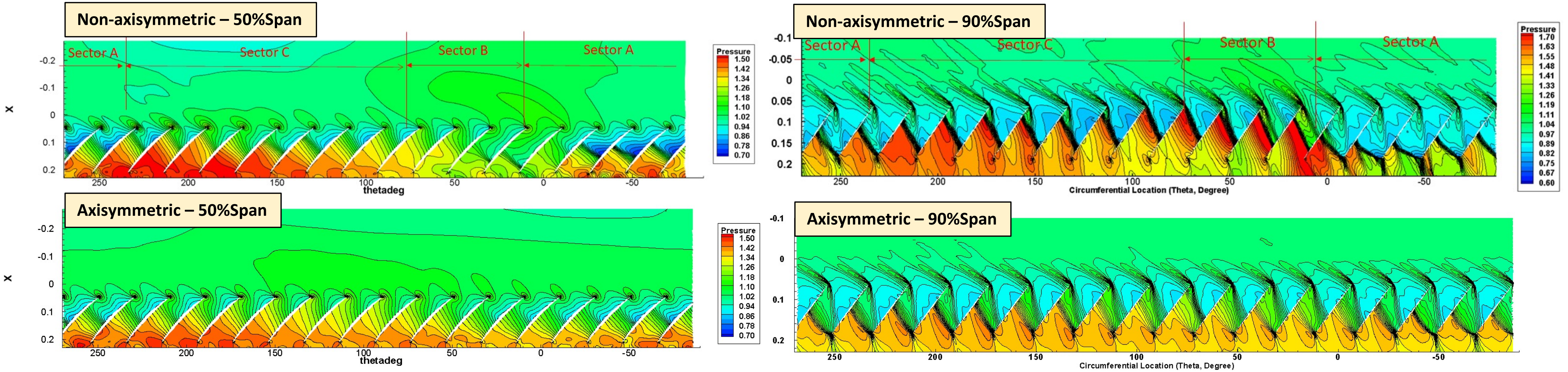


Performance map of the NASA's in-house developed DTF fan – full annulus URANS

Distortion Tolerant Fan (DTF) Stage Design

- The efficiency penalty due to the non-axisymmetric profile is about -2.2%, and the choking mass flow rate difference is about 2% less than the axisymmetric profile data.
- Significant spatial variation of each rotor's flow pattern can be observed.

Blade to Blade view of full annulus fan CFD model with Non-axisymmetric Inlet Profile



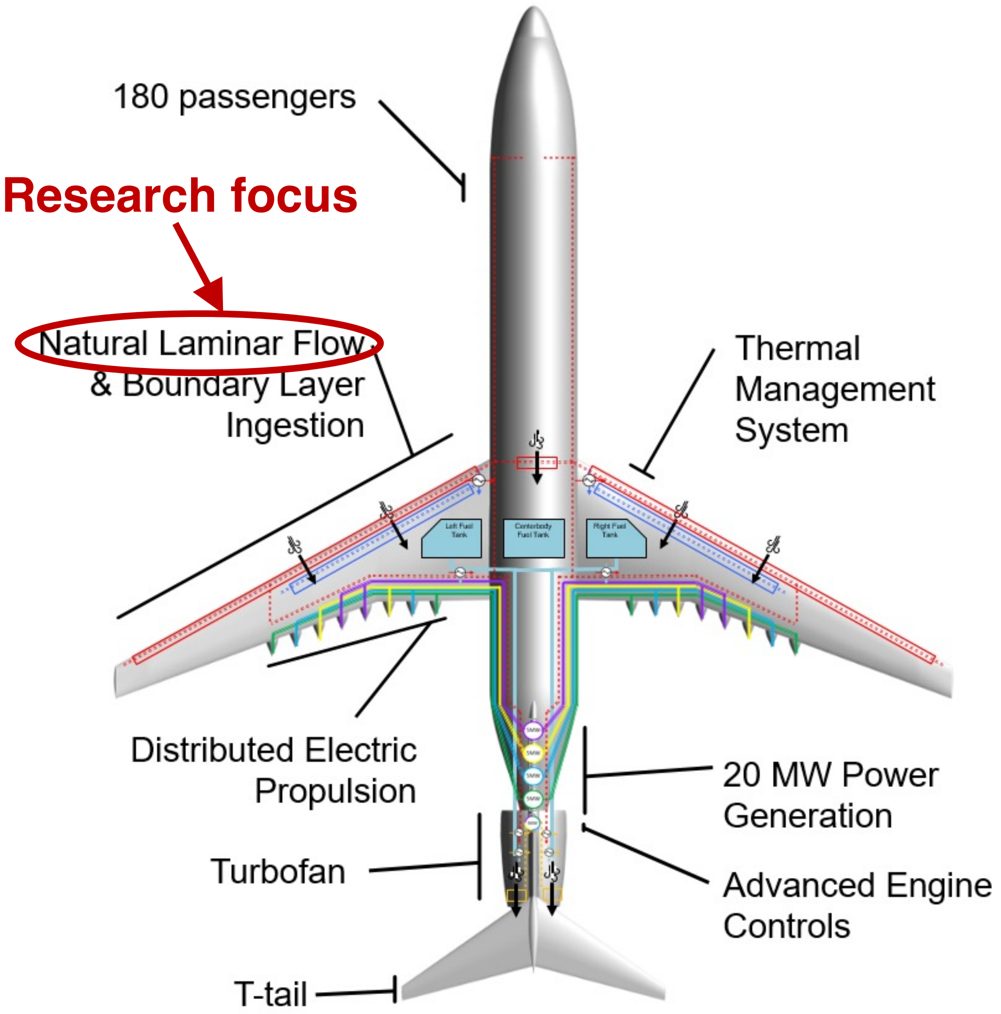
Conclusions

- Conceptual designs of the propulsion modules for the SUSAN electro-fan aircraft are presented.
- Turbo-electric Distributed Propulsor
  - The TeDP systems adopt sixteen distributed engines and share 2/3 of the total thrust requirement.
  - Eight engine modules are installed on each wing and enclosed in a mail-slot type nacelle.
  - Each unit requires about 0.56MW shaft power at the 37,000 ft altitude condition.
  - By adopting BLI propulsion technology, the shaft power requirement can be reduced to 0.41~0.49MW levels depending on the configurations that correspond to about 13~23% of power saving with the ideal propulsor assumption.
  - Low-speed low-pressure counter-rotating fans (CRFs) are adopted as part of the effort to minimize the distortion penalty.
- Tail-mounted Turbofan Engine
  - The reason why high fidelity PAI CFD should involve even in the system design process is discussed, and an example of the sizing of BLI engine and core ducts using CFD driven profiles.
  - Integration of nacelle with a vertical tail of the aircraft and the role of IGVs in controlling the incoming swirl distortions are addressed.
  - CFD analyses and the baseline fan stage performance are assessed to estimate the distortion penalty from Type II distortion from the fuselage.

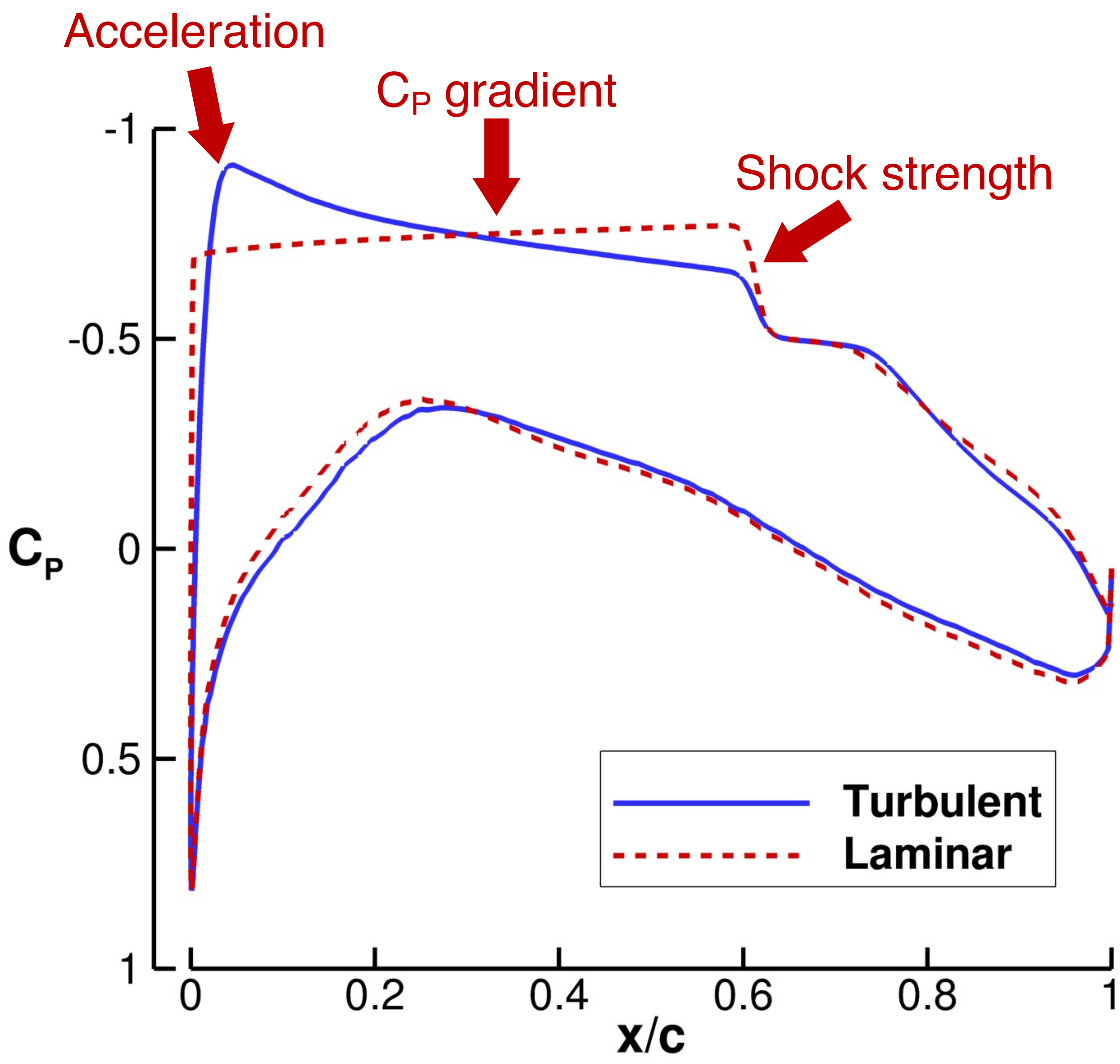
Design Exploration of Natural Laminar Flow Wings

Natural Laminar Flow Wings

- Natural laminar flow (NLF) study objectives:
  1. Quantify performance potential available from NLF wings
  2. Identify multidisciplinary impact of NLF wings
- Laminar flow significantly improves vehicle performance, but NLF has been limited to components with low sweep and Reynolds number
- Method chosen to address crossflow instabilities on wing: **C**rossflow **At**tenuated **N**atural **L**aminar **F**low (CATNLF) airfoils
- CATNLF airfoils are designed to obtain pressure distributions that delay transition by damping leading-edge crossflow instabilities



Example Design Target Pressures



Notable differences:

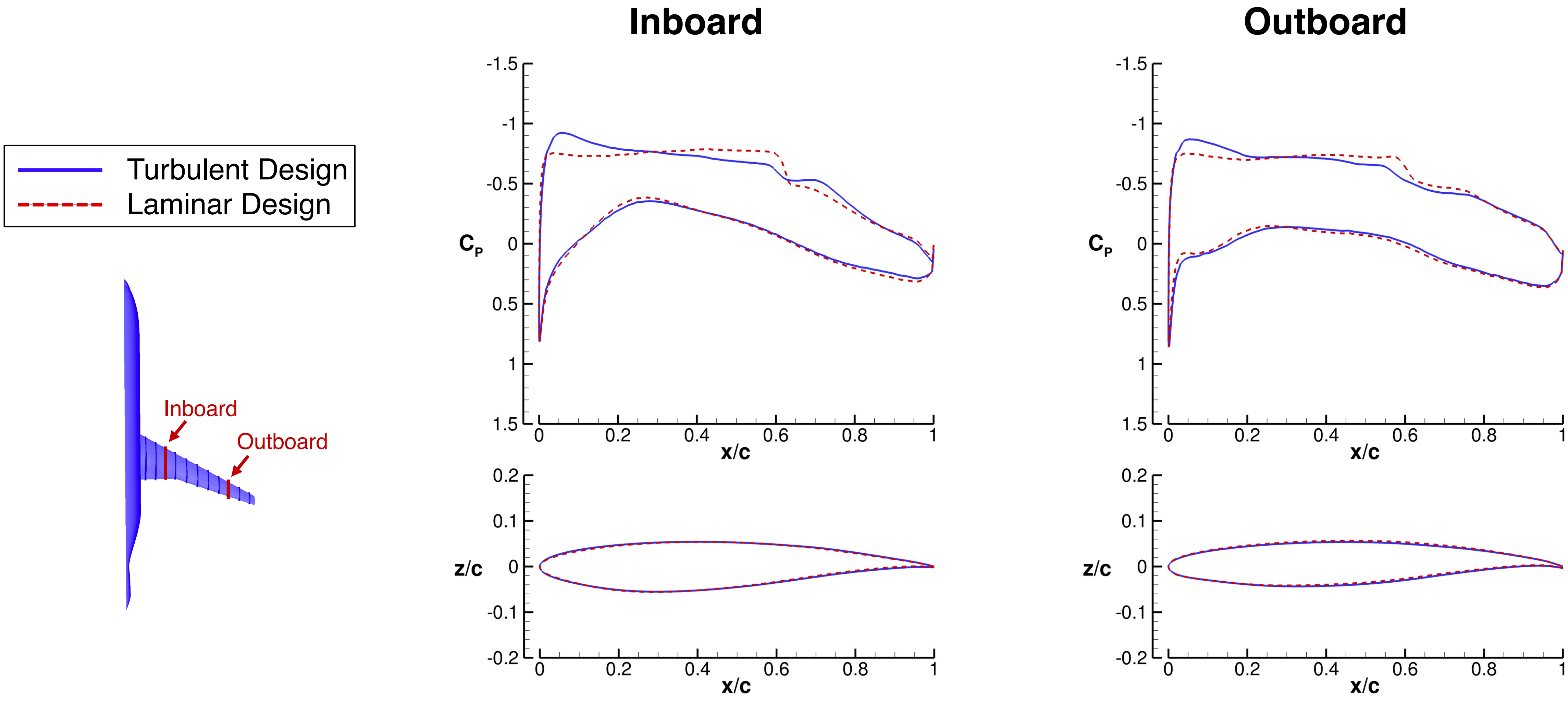
- Leading-edge acceleration
  - Laminar uses rapid acceleration for crossflow control
- Rooftop pressure gradient
  - Laminar uses mild favorable gradient for Tollmien-Schlichting control
  - Turbulent uses mild adverse gradient for shock strength reduction
- Shock strength
  - Turbulent has weaker shock

Computational Tools

- **Design Module: *CDISC***
  - Applies knowledge-based design rules to change geometry to match target pressure distributions
- **Flow Solver: *USM3D***
  - Solves Navier-Stokes equations on unstructured tetrahedral grid
- **Boundary Layer Profile Solver: *BLSTA3D***
  - Calculates boundary layer velocity and temperature profiles based on chordwise pressure distribution assuming conical flow
- **Boundary Layer Stability Analysis: *LASTRAC***
  - Stability analysis and transition prediction using e^N Linear Stability Theory method with compressibility effects

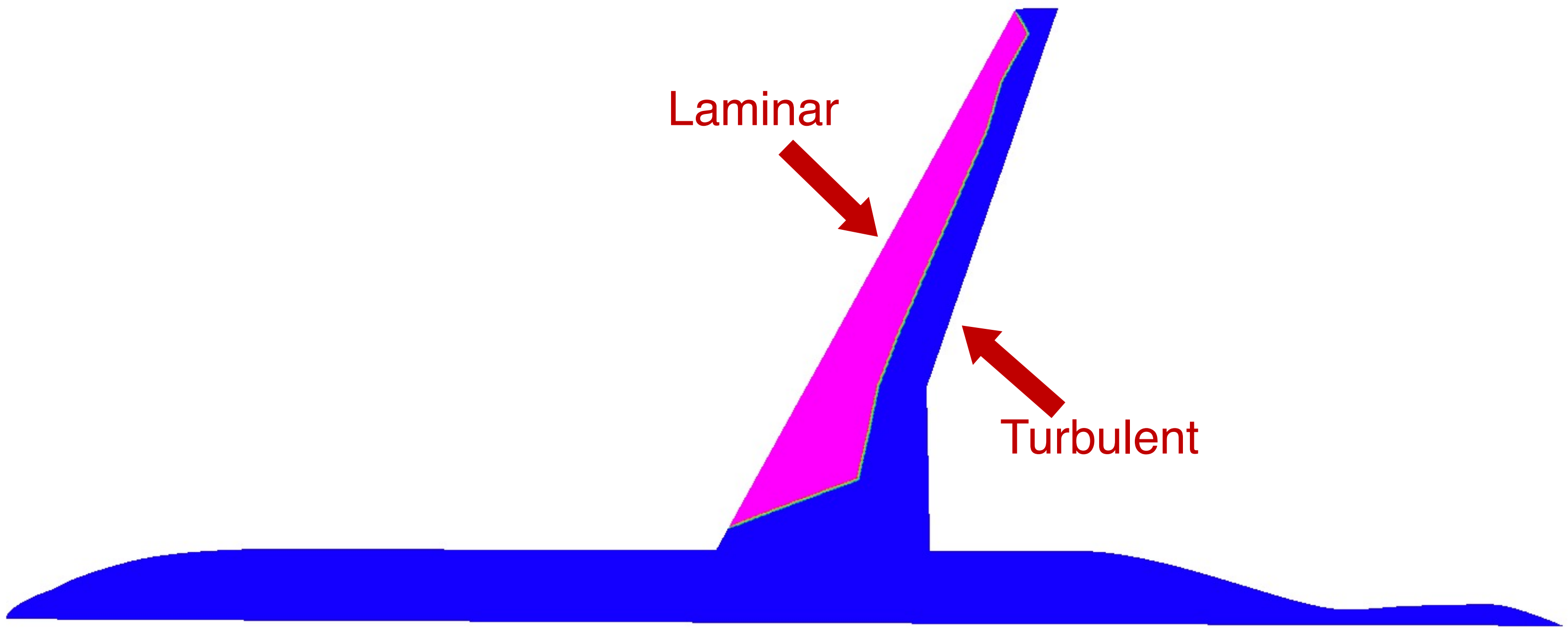
Design Results: Geometry and Airfoils

Mach = 0.785, C_L = 0.50, Altitude = 37,000 ft, Re_{MAC} = 23.1 x10^6



Design Results: Laminar Flow Characteristics

Laminar Design supports laminar flow on approximately 53% of the surface area on the wing upper surface



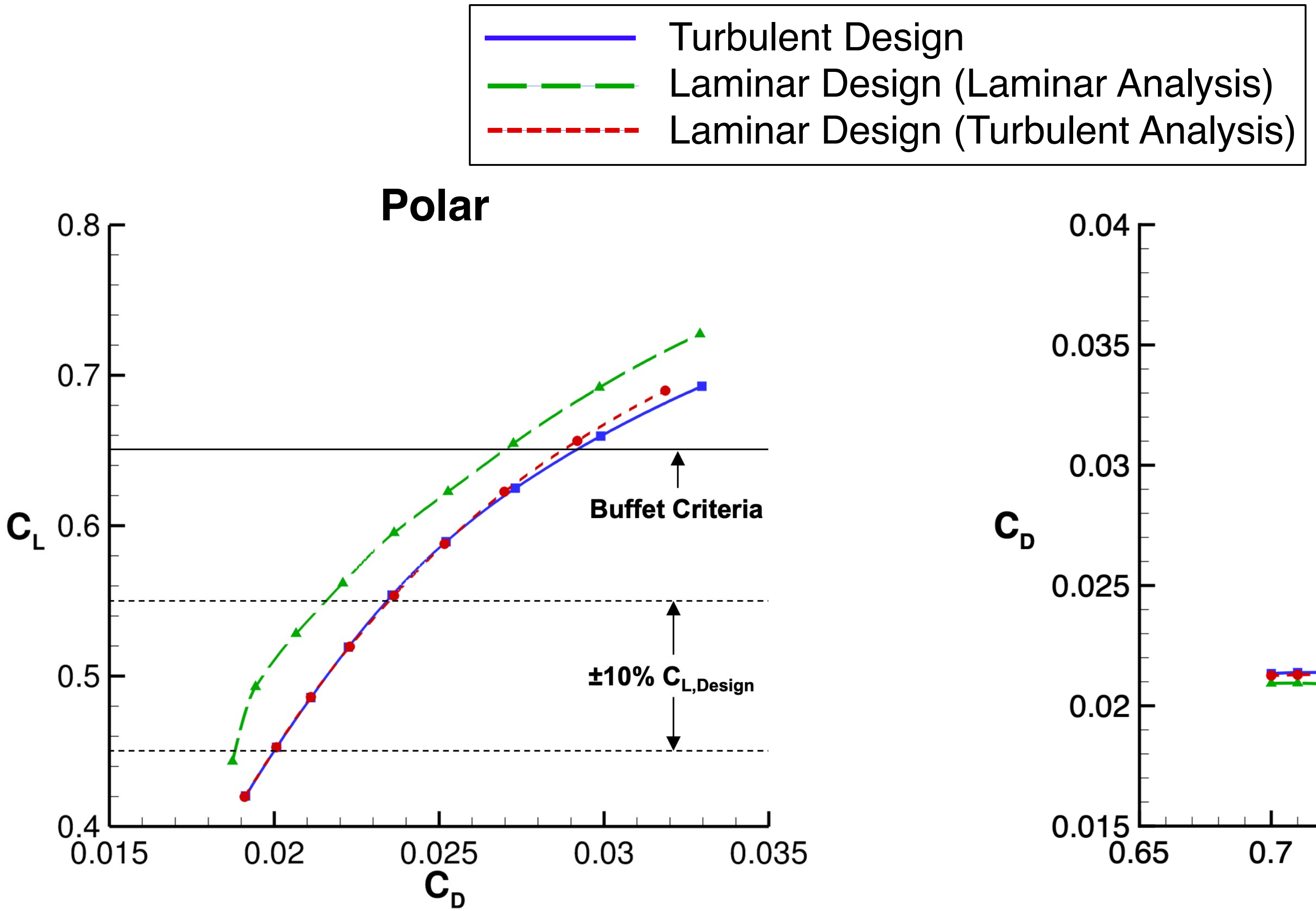
Design Results: Laminar Flow Characteristics

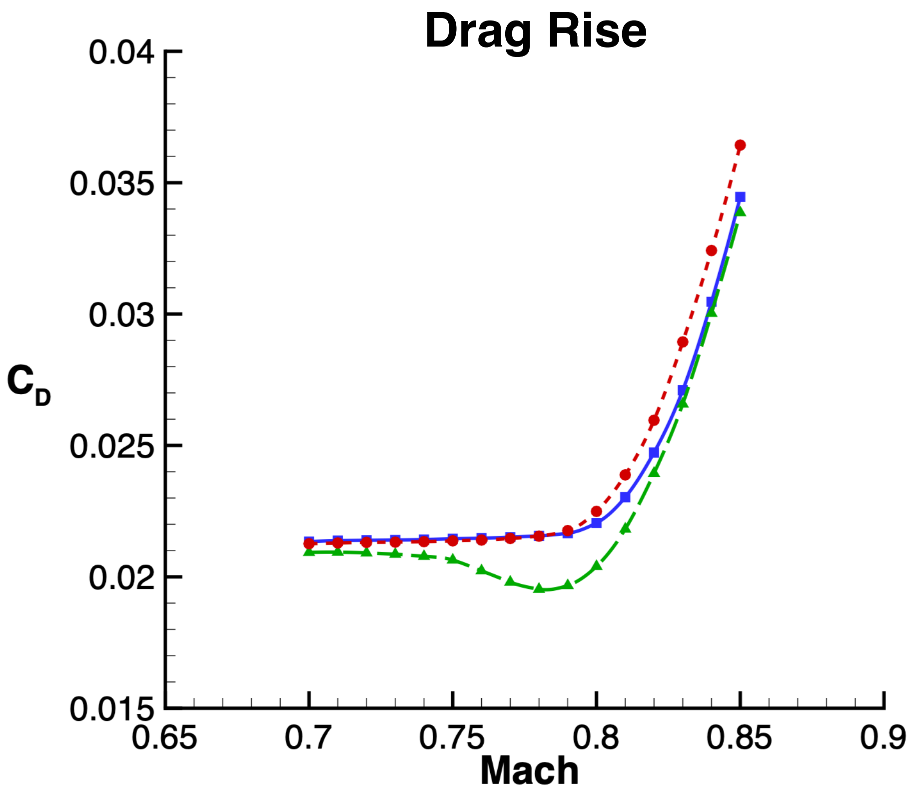
Configuration	C_L	C_D	C_m	ML/D
Turbulent Design	0.500	0.0216	-0.281	18.17
Laminar Design (Laminar Analysis)	0.500	0.0197	-0.309	19.92
Laminar Design (Turbulent Analysis)	0.500	0.0216	-0.291	18.17

- Laminar Design reduced drag by 19 counts (8.8%) from Turbulent Design
- Total loss of laminar flow on Laminar Design would result in:
  - No performance change from Turbulent Design
  - Drag increase of 19 counts (8.8%) from Laminar Design

Design Results: Laminar Flow Characteristics

Laminar Design shows sustained performance improvement across near-cruise off-design range





Multidisciplinary Considerations of NLF

- **General NLF considerations:**
  - Surface finish requirements ➔ additional manufacturing and maintenance costs
  - Smooth surface requirement ➔ wing upper surface must be free of all steps and gaps

- **SUSAN Electrofan considerations:**
  - Impact of wing-mounted engines on NLF:
    - Engines can cause forward shock movement ➔ limit possible NLF extent
    - Engines may increase turbulence/noise in boundary layer ➔ reduced NLF extent
  - Impact of NLF on wing-mounted engines:
    - NLF thins boundary layer ➔ reduced Boundary Layer Ingestion (BLI) benefit
    - NLF loss changes boundary layer thickness ➔ BLI benefit changes during operation

Summary and Future Work

- CATNLF design process applied to the SUSAN Electrofan regional jet configuration
- NLF study objectives:
  - Quantify performance potential available from NLF wings
  - Identify multidisciplinary impact of NLF wings
- Laminar Design supports 53% laminar flow on the wing upper surface providing an 8.8% decrease in drag for the wing-fuselage configuration
- Off-design characteristics show robust design with sustained laminar flow benefit
- Potential reduction in benefit from interaction between NLF and wing-mounted engines
- Future work:
  - Design wing with wing-mounted engines
  - Explore NLF on other surfaces such as nacelles, tail, nose, etc.

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- Convergent Aeronautics Solutions (CAS) Project under NASA ARMD's Transformative Aeronautics Concepts Program (TACP)
- NASA Advanced Supercomputing (NAS) Division
- The SUSAN Electrofan Team

Selected Modeling & Simulation Presentations

Conceptual Exploration of Aircraft Configurations (AIAA 2022-2181)

Timothy Chau, Gaetan Kenway, and Cetin Kiris
NASA Ames Research Center

High-Fidelity Aerodynamic Analysis of Propulsion and Airframe Integration Technologies (AIAA 2022-2304)

Leonardo Machado, Jared Duensing, Timothy Chau, Gaetan Kenway, and Cetin Kiris
NASA Ames Research Center

High-Fidelity Design and Analysis of Propulsion Systems (AIAA 2022-2305)

Byung Joon Lee and May-Fun Liou
NASA Glenn Research Center

Design Exploration of Natural Laminar Flow Wings (AIAA 2022-2303)

Michelle Lynde, Richard Campbell, and Brett Hiller
NASA Langley Research Center

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